Grasshoppers of azonal riparian corridors and their response to land transformation in the Cape Floristic Region

by

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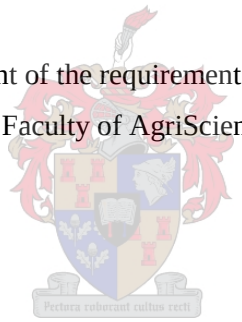

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Declaration

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Aan my Ouers, Broer en Smokey

Overall summary

The Cape Floristic Region (CFR) is a global biodiversity hotspot with high levels of endemism across many taxa, including Orthoptera. Azonal vegetation, a much forgotten component of the CFR, is a unique vegetation type that forms part of the riparian corridor. This is a complex, unique and diverse ecosystem with high levels of local biodiversity that connects the aquatic and terrestrial realms. The riparian corridor is highly disturbed through anthropogenic activities and invasion by alien vegetation causing deterioration of riparian corridors. Most natural riparian corridors are now confined to the mountainous slopes and higher elevations. Grasshopper assemblages are good bioindicators of environmental change and habitat deterioration. In response to this I determined the grasshopper assemblage which characterizes the natural riparian and adjacent terrestrial zone and their dispersion across the two zones. I also investigated how grasshoppers respond to riparian corridor disturbances (land transformation) and if they are viable candidates for bioindication of riparian corridors.

In Chapter 2 I investigated the ecology of grasshoppers (Orthoptera: Acridoidea) within a non-biome specific natural riparian zone along an important river in the CFR (Lourens River). Grasshopper sampling took place in the natural riparian and terrestrial zones along seven sampling units (SU's) that were 25 m in length and 35 m wide, in both the riparian and terrestrial zones. The riparian sites were along the river in the riparian corridor whereas the terrestrial sites were farther away. I did find a significant difference between the natural riparian and terrestrial grasshopper assemblages, but I indicated that grasshopper abundance and species richness may be more associated with the riparian vegetation.

In Chapter 3, I investigated how grasshoppers respond to land transformation along the riparian corridor of an important river in the CFR (Lourens River), whilst investigating the possibility of grasshoppers as bioindicators. Grasshopper sampling took place in different land use types (LUTs) (natural, agricultural, cleared of invasive alien-trees, invaded by alien-trees and an urbanized riparian area) along the riparian corridor. Each LUT had seven SU's per site where grasshopper sampling took place (as per Chapter 2). I found that grasshopper diversity is significantly influenced by the different LUTs and no CFR endemic grasshoppers were present within the invaded or urbanized riparian area. I found that the agricultural and cleared riparian areas had the highest abundance of grasshoppers and were most speciose with a great abundance of CFR endemic grasshoppers. I found that the cleared riparian LUTs had the most CFR endemic grasshopper richness and abundance. In general I found that grasshoppers respond to the different LUTs.

In conclusion, there exists a riparian grasshopper assemblage in the natural riparian zone of the CFR. Conservation is hereby critical in this area as it adds to the biodiversity of the region. Land uses had significant influences on grasshopper assemblages, especially on CFR endemic grasshoppers along the riparian corridor. The conservation and maintenance of the mixture between riparian and fynbos plants are important for grasshopper assemblages and more so for the persistence of CFR endemic grasshoppers. Riparian corridor conservation and maintenance is critical for the maintenance and enhancement of grasshopper biodiversity in a biodiversity hotspot, the CFR.

Algehele samevatting

Die Kaapse Floristiese Streek (KFS) is 'n wêreldwye kuberkol biodiversiteit met hoë vlakke van endemisme oor baie taksons, insluitend Orthoptera. Azonal plantegroei, 'n veel vergete deel van die KFS, is 'n unieke tipe plantegroei. Die azonal plantegroei vorm deel van die rivieroewers gang wat kompleks, uniek en 'n diverse ekosisteem met hoë vlakke van plaaslike biodiversiteit asook ‘n verbinding is tussen die land- en akwatiese ryke. Die oewergebied gang is hoogs versteur deur menslike aktiwiteite en inval deur indringerplante dit veroorsaak agteruitgang van rivieroewers gange. Mees natuurlike rivieroewers gange is nou beperk tot die berghellings en hoër hoogtes. Sprinkaan versamelinge is goeie bioindicatoren vir omgewing verandering en habitat agteruitgang. In reaksie op hierdie bepaal ek die sprinkaan versameling wat die natuurlike oewereienaars en aangrensende landelike gebied karaktiseer en hulle verspreiding oor die twee sones. Ek ondersoek ook hoe sprinkane reageer op rivieroewers gang versteurings (land transformasie) en as daar lewensvatbare kandidate vir bioindication van rivieroewers gange bestaan.

In Hoofstuk 2 ondersoek ek die ekologie van sprinkane (Orthoptera: Acrididoidea) binne 'n nie-bioom spesifieke natuurlike oewersone langs 'n belangrike rivier in die KFS (Lourens River). Sprinkaan monsterneming het plaasgevind in die natuurlike rivieroewers en terrestriële sones langs sewe monsterneming eenhede (US) wat 25 m in lengte en 35 m breed was, in beide die rivieroewers en aardse sone. Die oewergebied terreine is langs die rivier in die rivieroewers gang terwyl die aardse terreine verder weg is. Ek het 'n ‘n groot verskil tussen die natuurlike en aardse rivieroewers sprinkaan versameling gevind, maar ek toon aan dat sprinkaan oorvloed en sort rykste miskien ‘n assosiasie het met die plantegroei van die rivieroewers.

In Hoofstuk 3 ondersoek ek hoe sprinkane reageer op land transformasie langs die rivieroewers gang van 'n belangrike rivier in die KFS (Lourens River), terwyl ek ondersoek na die moontlikheid van sprinkane as bioindicatoren. Sprinkaan monsterneming het plaasgevind in verskillende tipes grondgebruike (LUTs) (natuurlike, landbou, verwydering van uitheemse bome, binnegeval deur uitheemse bome en 'n verstedelikte rivieroewers area) langs die rivieroewers gang. Elke LUT het sewe US per staanplek waar sprinkaan monsterneming plaasgevind het (soos per Hoofstuk 2). Ek het gevind dat sprinkaan diversiteit aansienlik beïnvloed word deur die verskillende LUTs en geen KFS endemiese sprinkane teenwoordig is in die binnegeval of verstedelikte rivieroewers gebied was. Ek het gevind dat die landbou- en skoongemaak oewergebiede het die hoogste oorvloed van sprinkane en mees soort rykste is met 'n groot menigte van KFS endemiese sprinkane. In die algemeen het ek gevind dat sprinkane reageer op die verskillende LUTs.

Ten slotte, is daar 'n spesifieke rivieroewers sprinkaan fauna in die natuurlike oewersone van die KFS. Bewaring is hiermee krities in hierdie gebied as dit voeg om die biodiversiteit van die streek. landgebruike toon ‘n beduidende invloed op sprinkaan versamelinge, veral op die KFS endemiese sprinkane langs die rivieroewers gang. Die bewaring en instandhouding van die mengsel tussen oewereienaars en fynbos plante is belangrik vir sprinkaan versameling en meer so vir die voortbestaan van die KFS endemiese sprinkane. Rivieroewers gang bewaring en instandhouding is van kritieke belang vir die instandhouding en verbetering van sprinkaan biodiversiteit in 'n biodiversiteit kuberkol, die KFS.

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Bianca Mignon Pronk, December 2015.

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Grasshoppers of azonal riparian corridors and their response to land transformation in the Cape Floristic Region

Chapter 1: General introduction

Global biodiversity crisis

Ecosystems globally are undergoing rapid change (MEA 2005), as well as experiencing accelerated losses of biodiversity (Sodhi and Ehrlich 2010). Main drivers of global environmental change and biodiversity loss consist of CO_2 enrichment, climate change, biotic invasions, increased deposition of nitrogen, and especially habitat loss and land transformation (Tylianakis *et al.* 2008; Laurance 2010). It is predicted that these drivers are becoming increasingly important as human exploitation of the environment increases (Sala *et al.* 2000), with increasing loss of species (Pimm and Raven 2000). Through the process of landscape fragmentation, while much of the land is transformed, remnants still remain, with riparian zones faring better than most other landscape elements.

Globally, agriculture has been deemed the biggest cause of habitat destruction. However, mining, clear-cut logging, the invasion of alien trees and urban sprawl are also capable of destroying or immensely degrading habitat as well as habitat quality (Sodhi and Ehrlich 2010). Therefore, it can be implied that global environmental change is driven by a complex response to numerous anthropogenic-induced modifications in the global environment (Vitousek 1994). These drivers are most likely to cause extinctions as well as alter the distribution of species, as these drivers have been shown to impact on numerous antagonistic and mutualistic interactions among species (Tylianakis *et al.* 2008). Hence, biodiversity change is now considered, in its own right, as a significant global change (Walker and Steffen 1996), as a consequence of the magnitude of the change (Pimm *et al.* 1995), as well as it being strongly linked to changed ecosystem processes and functioning (Walker and Steffen 1996; Daily 1997).

Urban populations also have the capacity to not only alter ecosystems within the area they occupy, but they have the capacity to alter ecosystems which are sometimes even a few hundred km away (Cincotta *et al.* 2000). This happens through the demand for wood fuel, waste disposal, water, food and recreation (Cincotta *et al.* 2000). Furthermore, the disturbances created by humans can even occur in the absence of a widespread human settlement (Cincotta *et al.* 2000). This results from frequent over-logging practices, mining, grazing and even commercial hunting which have extracted and degraded natural resources, encouraged biological invasion as well as soil and water pollution (Cincotta *et al.* 2000). Throughout the world's biomes and ecoregions, natural ecosystems have been sustaining essential ecological functions

that support biodiversity (Bazzaz 1996). Moreover, they provide valuable ecosystem services such as erosion control and water retention which in turn benefits and sustains human populations and agricultural activities (Daily 1997). Therefore, as human activities degrade the world's biomes, we diminish the variety of landscapes (homogenizing the landscape), ecological interactions, the evolutionary pressures that sustain biodiversity (Bazzaz 1996) and ecosystems services that are provided to benefit humans (Daily 1997).

Human activities alter natural disturbance regimes through the introduction of new disturbances (Nystrom *et al.* 2000), such as invasive alien species, or even by suppressing or removing natural disturbances (Nystrom *et al.* 2000), such as natural fire regimes/cycles. Furthermore, human disturbances are altering the capacity of ecosystems to cope with disturbances (Nystrom *et al.* 2000), which may in turn lead to endemic and specialized species becoming lost and even extinct due to habitat fragmentation, land transformations, habitat loss, decrease in habitat quality and consequently leading to the reduction of functional diversity.

The Cape Floristic Region

Mediterranean-type ecosystems (MTEs) are among the best studied worldwide, particularly because of their outstanding biodiversity, second next only to the tropics (Cowling et al. 1996). Mediterranean-type ecosystems have been proposed as model systems for the study of global change impacts, as they offer the possibility of investigations into the various interactions among climatic, atmospheric and land use changes (Lavorel *et al.* 1998). MTEs also offer the opportunity to focus on land use, and how it may interact with ecological diversity as well as on atmospheric and climatic changes (Lavorel *et al.* 1998).

Globally there are only five MTEs, which occupy <5% of the earth's surface, yet contain about 48 250 known vascular plant species (Cowling *et al.* 1996). Furthermore, they also have exceptionally high plant endemism and diversity (Cowling *et al.* 1996). Among these MTEs is the Cape Floristic Region (CFR), confined to the Western Cape of South Africa between latitudes of 31.00˚ and 34.30°S, with a typical MTE climate with hot, dry summers and cool, wet winters (Goldblatt and Manning 2000; Giliomee 2003).

South Africa is one of the world's foremost centers of both plant endemism and diversity, with the greatest concentration of plant species occurring in a sclerophyllous and fire-prone shrubland that is known as the fynbos. The fynbos predominantly dominates the south-western corner of the country, but is however intermixed with enclaves of other biomes and is referred to as the Cape Floristic Region (the CFR) (Sieben 2000; Goldblatt and Manning 2000; Proçhes and Cowling 2006). The CFR is one of the

world's sixth and smallest floristic kingdoms of the world (Fourie and Müller 2011), and has the greatest concentration of plant species in the world. The CFR is small, covering an area of only 90 000 km^2, about 4% of South Africa. It has high levels of plant endemism when compared to most, if not all equivalent-sized regions of the world (Goldblatt and Manning 2002; Linder 2003; Kreft and Jetz 2007). The CFR contains >13 000 plant species, and has been recognized as a global biodiversity hotspot owing to its high floral richness and endemism (70%), including five endemic families (Goldblatt and Manning 2000), as well as because of the high level of threat to its biota (Cowling *et al.* 1992; Myers *et al.* 2000). The main families that contribute to the vegetation of the CFR belong to the families Proteaceae, Ericaceae and Restionaceae, which adds to the uniqueness of the CFR as this combination is not as diverse anywhere else in the world (Sieben 2000).

Many of the vegetation types outside the mountain catchment areas are highly transformed by agriculture, urbanization and invasive alien vegetation as a result of poor conservation action (Rebelo 1992). Within the CFR, the fynbos biome is the major eco-region constituent of the CFR, with about 66% of South Africa's 21 "Critically Endangered" terrestrial ecosystems (Driver *et al.* 2005).

The speciose vegetation of the CFR, including its high level of endemism has mainly been associated with the fynbos biome, although other vegetation types, such as thickets, forests, succulent and Nama karoo vegetation, also play a role in contributing to its diversity (Low and Rebelo 1996). In addition, the surrounding coastal areas also support significant CFR biodiversity (Turpie *et al.* 2000). The fynbos biome is a sclerophyllous, fire-prone shrubland with an exceptionally and extraordinary species-rich flora (Proçhes and Cowling 2006; Wright and Samways 1998). Characteristically, the fynbos has low-nutrient demanding plants that grow on very nutrient-poor, infertile, sandy soils (Wright and Samways 1998). The extreme floral diversity associated with the fynbos is due mainly to the topographic heterogeneity of the region, long-term climatic stability and because of its fire-driven ecological dynamics (Mucina and Rutherford 2006).

The CFR has been extensively studied for its unique richness in plant diversity and endemism (Reinecke 2008). However, little has been done on the faunal richness and endemism within the CFR, especially so in the case of the invertebrates. The fauna of the CFR is not equivalent to the flora, both in terms of species richness and endemism (Cottrell 1985; Johnson 1992; Giliomee 2003). Even though numerous animal endemic species do occur within the CFR, the overall proportion, when compared to plants, is low. Moreover, the vertebrates of the CFR have a lower diversity when compared to the subtropical regions to the north-east of the CFR (Low 1998), while the situation with CFR invertebrate diversity relative to plant diversity still requires further research (Wright and Samways 1998; Proçhes and Cowling

2006; Kuhlmann 2009; Proçhes *et al.* 2009). Nonetheless, the biodiversity, and hence the ecosystem services that the area provides, is critical to the CFR as it helps to sustain the natural resource base.

It has been suggested that the fynbos biome has a relatively poor insect fauna relative to that of plants (Johnson 1992; Giliomee 2003), suggesting a deviation from the general large-scale relationship between the diversity of plants versus insects (Hawkins and Porter 2003). The supposedly low insect diversity has been attributed to the fact that fynbos vegetation has defenses against phytophagous invertebrates, such as chemical defense and sclerophylly (Johnson 1992; Giliomee 2003). However, the few studies that have been done do not support this contention as the studies were limited to small sets of plant species (Proçhes and Cowling 2006). Even though the sclerophyllous leaves of fynbos plants may be a deterrent to most phytophagous insects (Giliomee 2003), along with the low nutrient of the plants (as a result of nutrient poor infertile soils), could conversely, favor generalist phytophagous invertebrates which are capable of switching seasonally between plant species so as to optimize their nutrient uptake (Augustyn *et al.* 2013). Alternatively, phytophagous insects may be plant species specialists and consequently only be present within the environment when nutrient uptake is most optimal (Kemp 2014). For instance, the leafhopper species in the tribe Cephalelini (Cicadellidae) have been recorded to be a specialist on the plant family Restionaceae (Davies 1988; Augustyn *et al.* 2013), which suggests that some vegetation types may have a higher nutritional value than others. This may be the case for riparian vegetation in the CFR and where specialist species may even include endemic invertebrates. For instance, the genus *Bestiscoides* of the family Lentulidae is a Cape endemic grasshopper which is strongly specialized on the plant family Restionaceae (Key 1937; Matenaar *et al. 2014*).

Proçhes and Cowling (2006) have suggested that there is not low insect diversity compared to that of plants in the fynbos, and that high diversity has been recorded, contradicting earlier studies. Recent studies support this contention, as there is high diversity in gall-insects (e.g. Hemiptera: Psyllidae; Coleoptera: Apionidae; Diptera; Tephritidae) (Wright and Samways 1998) and bees (Kuhlman 2009). Insect diversity levels within the fynbos is remarkably similar to that in grassland (Proçhes and Cowling 2006). Nonetheless, the CFR is particularly rich in endemic insect species and parallels that of plant diversity (Linder 2003; Proçhes and Cowling 2006), but differs for different families of insects (Davies 1988; Wright and Samways 1998).

Cape Floristic Region under pressure

MTEs span the coastal and interior portions of California, Mexico and USA, Chile, Australia, the Mediterranean Basin and South Africa where they are all under threat (Underwood *et al.* 2009). MTEs may undergo the greatest estimated proportional change in biodiversity by 2100, due to their sensitivity to

climate and land use change (Sala *et al.* 2000). Correlations have been made between human population density and biodiversity, with Cincotta *et al.* (2000) estimating that the human population growth rate within MTE biodiversity hotspots is 1.8% per annum compared to the global average of 1.3% (Underwood *et al.* 2009). According to Balmford *et al.* (2001), there is a positive correlation between population density and areas of high species and threatened species richness within the African continent. Of the MTEs, the CFR has the second-highest human population growth rate after Chile (Underwood *et al.* 2009). Conversion of natural areas to urban and high intensity agriculture is one of the greatest transformations currently taking place (Hoekstra *et al.* 2005; Miles *et al.* 2006). Other threats such as population density and growth of urban areas (Rouget *et al.* 2003; Schwartz *et al.* 2006), conversion to agricultural land (Hobbs 1998) and the conversion and utilization of natural areas for tourism-related development threatens MTE biodiversity (Grenon and Batisse 1989; Paskoff and Manriquez 1999).

Globally, 21.8% of land area has been converted to human dominated uses, with habitat loss being most extensive in tropical dry forests and Mediterranean forests, woodland and scrub (Hoekstra *et al.* 2005). Temperate grasslands and savanna as well as mediterranean forests, woodlands and scrub are at greatest risk because of the extensive loss in habitat, which exceeds that of habitat protection (Hoekstra *et al.* 2005). The CFR does not differ from other parts of the world in that the prevailing conservation areas do not effectively conserve the rich biodiversity of this region (Rebelo 1997).

Predicted threats in the CFR are those associated with agricultural transformation, urbanization and especially the establishment of stand of alien trees and shrubs, particularly species of the genus *Pinus, Acacia, Hakea, Leptospermum* and *Eucalyptus*, all of which are known to greatly affect the functioning and structure of many CFR ecosystems (Higgins *et al.* 1999; Turpie et al. 2003), with fynbos biodiversity loss becoming severe (Hoffman 1997). Almost half (46%) of the vegetation types found within the CFR are considered to be threatened by habitat transformation (Rouget *et al.* 2004; Driver *et al.* 2005). In addition, 21 of the 23 national Critically Endangered vegetation types occur within the CFR, according to the latest ecosystem assessment (Government of South Africa 2009). Invasive plants displace natural vegetation, with at least two-thirds of the remaining fynbos been infested with alien invasive plants, with 13% having alien cover of >25% (Rouget *et al.* 2003). Not only does invasive vegetation displace the natural vegetation, but it is one of the major consumers of water in the CFR (Turpie *et al.* 2003).

Riparian Zone

Azonal vegetation is characterized by not being reliant on the climatic zone but are adapted to specific habitat types that occur across different climatic regions and are vegetated by specialized plant species (Sieben 2000). Examples of azonal vegetation include saltmarshes, coastal vegetation, rocky outcrops and

aquatic vegetation (Sieben 2000). Riparian vegetation also largely belongs to this category (Sieben 2000). . Rivers are associated with riparian corridors that retain a 'certain'riparian vegetation type and even though rivers flow through the vegetation of a biome which may contain many biome-specific plant species, the riparian zones also support their own particular and distinct vegetation, which differs both in structure and function from the adjacent aquatic and terrestrial environments (Sieben 2000; Holmes *et al.* 2005). Vegetation of the riparian zone has both biome-specific and non-biome specific plant species and it also has plants associated with hydrological, geomorphological and disturbance regimes (Naiman *et al.* 1993; Decamps *et al.* 1995; Cooper *et al.* 2003). Hereby, the natural riparian zones are open to numerous disturbances and changes that alter and shape the riparian vegetation. This emphasizes how the natural riparian zones are among the most complex, diverse and dynamic biophysical habitats in the terrestrial environment (Naiman *et al.* 1993; Tang and Montgomery 1995).

Riverine ecosystems are among the most complex and diverse in the world, and have been described by Day *et al.* (1986) as having four dimensions: (1) the longitudinal axis of the entire river, (2) the profile of the riverbed itself, (3) the elevation of the water level, and (4) the time scale. Riparian zones next to the river are very dynamic, as they are subject to disturbances coming from the river and those from the surrounding uplands. Such disturbances include herbivory, disease, fire, invasion and agriculture, making them heterogeneous environments encapsulating numerous niche possibilities (Gregory *et al.* 1991; Sieben 2000). Both the river and the riparian zone reflect the environmental heterogeneity of the catchment area because many nutrients occurring in the substrate of the catchment find their way into the river (Rogers and van der Zel 1989; Naiman and Decamps 1997), whereas the riparian vegetation is also reliant on the underlying substrate (Sieben 2000). This leads to the in-stream biota also being influenced by riparian vegetation through shading and nutrient inputs (King 1981; Stewart and Davies 1990; Stewart 1992). Thus the quality of riparian vegetation is of enormous importance as it influences the quality of the water and also the in-stream biota.

In a mosaic of landscapes, riparian ecosystems are predominantly the most central element within them (Nilsson and Jansson 1995) due to: (1) riparian ecosystems having a string-like shape as well as being arranged into dendritic drainage patterns (Forman and Godron 1986), effectively allowing them to be interspersed into the landscape despite their small coverage area; (2) being hotspots of species richness, making them the key element in both the regulation and maintenance of landscape diversity, both terrestrial and aquatic (Naiman *et al.* 1993); (3) acting as filters between adjacent landscape elements and consequently are indicative of environmental change (Naiman and Decamps 1990; Decamps 1993); and (4) being significant natural corridors for energy flow as well as the flow of matter and species throughout the landscape (Forman and Godron 1986; Malanson 1993). Therefore, they have significant ecological

properties which reach far beyond their spatial extent (Decamps *et al.* 2004). Thus, riparian zones are regarded as one of the biosphere's most complex ecological systems, while also being capable of maintaining the vitality of the landscape (Naiman and Decamps 1997).

Riparian zones constitute an interface between terrestrial and aquatic systems, while encompassing sharp environmental gradients, as well as ecological processes and communities (Naiman *et al.* 1993). This interface can also be described as an ecotone, boundary or transition zone (Naiman and Decamps 1990), which is stretched out across the landscape (Nilsson and Jansson 1995). Riparian ecosystems can also be defined as the stream channel between the low- and high-water marks, with the inclusion of the terrestrial landscape that lies above the high-water mark, where elevated water tables, extreme flooding and the capability of the soil to hold water have an influence on the vegetation composition (Naiman *et al.* 1993). This results in riparian vegetation occurring between these two main zones up the bank of the river, namely the wetbank and the drybank (Otto 2014). There is a clear transition present in riparian vegetation as it moves from the wetbank to the terrestrial environment (drybank) within the riparian zone. This transition forms part of the lateral zone where interactions occur within the riparian environment (Otto 2014). Furthermore, these two lateral zones can be divided into smaller lateral zones which are associated with flood recurrence levels (Reinecke and Brown 2013) and contain specific plant species associated with these flood levels (Reinecke *et al.* 2007; Sieben *et al.* 2009).

Precisely delineating the riparian zone is difficult, as the heterogeneity expressed by the array of life history strategies and successional patterns, as well as the functional attributes associated with riparian zones, depend on community composition and the environmental setting that operate on different temporal hierarchical scales (O'Neill *et al.* 1986). This emphasizes that not all riparian zones are of similar features, or of similar widths as the river changes along its length, with different vertical and lateral flow regimes (Naiman and Decamps 1997). A river undergoes longitudinal change from its source, where the landscape is usually narrow with steep valleys and as it runs its course through the landscape towards where it mouths out, the floodplains tend to widen, as described by the river continuum concept (Vannote *et al.* 1980) and the nutrient spiraling concept (Webster and Patten 1979). Therefore it is difficult to set a standard width for riparian zones for all rivers. Nonetheless, except for the broad floodplains, riparian zones are relatively narrow linear features that occur along rivers and streams across the landscape (Holmes *et al.*2005).

This ecotone between the aquatic and terrestrial environment has specifically significant ecological characteristics, especially with seasonal changes of dry-wet cycles (Decamps *et al.* 2004). The ecotone creates a highly productive and biodiverse corridor, with the riparian zone controlling the flow and

physiognomies of both nutrients and other minerals across the landscape, where it harbors rich and diverse species assemblages (Decamps *et al.* 2004). Another key feature of the riparian zone includes its capability to manifest early indications of global environmental change due to its sensitivity to any variation within the hydrological cycle (Decamps *et al.* 2004).

Within the larger landscape, riparian zones are an unusually diverse mosaic of landforms, environments and communities, and as a result can serve as a framework for understanding the diversity, organization and dynamics of communities associated with fluvial ecosystems (Naiman *et al.* 1988; Decamps 1997). Not only is riparian vegetation diverse and unique, but it also provides habitat for a broad assortment of terrestrial and aquatic fauna, where it functions in maintaining enhanced levels of biodiversity (Naiman *et al.* 1988). Riparian zones also have unusually high vascular plant species richness as well as encompassing a wide array of successional stages (Naiman *et al.* 1993; Tockner *et al.* 1997; Ward 1998). Riparian plant communities are biological 'processors' between the terrestrial-aquatic interface, as their responses to hydrological disturbances are widely recognized (Gurnell 1995; Haycock *et al.* 1997).

Riparian ecosystems are exceedingly rich in ecological processes (Sieben 2000), whereas the vegetation impacts numerous essential ecological functions in relation to both aquatic and terrestrial habitats via the provision of food, shelter, moderation of stream temperature, creating a buffer zone that functions as a filtering system for sediments while controlling nutrients and stabilizing stream banks (Barling and Moore 1994; Hood and Naiman 2000). It also creates corridors for the movement of biota, therefore serving as a pathway for dispersal and migration (Naiman and Decamps 1997), while fulfilling important roles for humans (Kemper 2001).

In riverine ecosystems, riparian vegetation also functions in the prevention of soil and bank erosion, hampering turbulent floods, consuming water, and also adding to both species and habitat diversity (Rogers and van der Zel 1989; Birkhead *et al.* 1996). Bank stability is indeed the most important functional role of riparian vegetation (Sieben and Reinecke 2008). A mosaic of non-equilibrium habitats are created within riparian zones along rivers due to their dynamic natural flow regimes which may be enclosed with exceptional floral and faunal diversity (Salo *et al.* 1986; Decamps *et al.* 2004). Adequate shelter and food is provided through riparian vegetation, which in turn promotes and enhances animal diversity not only within riparian zones, but also in adjacent aquatic and terrestrial habitats (Decamps *et al.* 2004). Therefore, riparian zones are key landscape components in the maintenance of alpha and gamma diversity (Naiman *et al.* 1993; Naiman *et al.* 2004). Riparian zones also act as a habitat for resident flora and fauna in the utmost linear patches while maintaining critical habitat for rare and threatened species (Naiman *et al.* 1988; Rosenberg *et al.* 1997).

The species that occur within riparian ecosystems are not only temporary species, but are true inhabitants that survive and reproduce there (Decamps *et al.* 2004). As a result, habitat function is the main driver for these high levels of biodiversity within these zones (Naiman *et al.* 1993). Thus, natural riparian ecosystems consist of a diversity of community types, especially with deciduous trees and shrubs occurring on a heterogeneous substrate while encompassing diverse faunal communities (Nilsson and Berggren 2000).

Within the Western Cape, numerous studies have been undertaken on riparian vegetation, such as how riparian vegetation changes temporally and spatially, how communities differ and change longitudinally, vegetation biogeochemistry, and how the lateral zones link with the flow of a river, with many of these having been done in the CFR (Sieben 2000; Naude 2012; Reinecke 2013, Otto 2014). In the CFR, riparian vegetation is usually dissimilar from the surrounding fire-prone fynbos vegetation, even though it occurs under the same climatic conditions (Boucher 1978), emphasizing the theory of azonal vegetation types and how they differ florally to biome-specific vegetation. Therefore, riparian zones may house specially adapted faunal species that do not occur within the adjacent terrestrial environment.

Numerous methodologies have been developed to determine the health, integrity and quality of rivers using macroinvertebrates as bioindicators (used within The River Continuum Concept), dragonflies (Dragonfly Biodiversity Index) as well as the South African Scoring System (SASS) (Sedell *et al.* 1989; Chutter 1994; Dallas 1997; Schindler *et al.* 2003; Simaika and Samways 2009; Simaika and Samways 2011). No comprehensive studies have specifically examined how the riparian vegetation influences invertebrate species, species turnover and composition along a river, and whether or not riparian invertebrates could be used as a successful tool for monitoring the quality and health of riparian areas. In the coastal forelands of the CFR, riparian vegetation downstream is largely transformed and degraded, and very few rivers between the foothills and the ocean remain undisturbed, emphasizing the urgent need for reference ecosystems for lowland riparian corridors (Holmes *et al.* 2005). Thus, biological indicators could be a useful tool in determining reference ecosystem sites within riparian corridors in the CFR.

Riparian zones under pressure

The conservation status of MTEs regions across the globe is very poor and biodiversity is under increasing severe pressures (Hobbs *et al.* 1995), especially through human-driven modification. Freshwater ecosystems are also under severe threat (Dudgeon *et al.* 2006). With the increase in human population size, more people are moving closer to waterways, leading to a decrease in land availability and an increase in land use, resulting in an increase in disturbances along freshwater ecosystems, which includes riparian zones. Worldwide, riparian zones have been the main focus of human inhabitation as

well as development over the centuries, resulting in direct and indirect degradation of the ecological integrity of these zones (Washitani 2001).

Land use is therefore expected to have the largest effect on not only freshwater ecosystems, but it also extensively modifies riparian zones even in terrestrial biomes that otherwise may be infrequently populated (Sala *et al.* 2000). Freshwater ecosystems have shown substantial impacts from not only land use, but also biotic exchange and climate change (Sala *et al.* 2000). Even though riparian zones are relatively small (Thomas 1979), these ecosystems are exceptionally vulnerable to severe alteration and disturbance. Not only are they vulnerable, but they should also be considered fragile, due to their distinctive vegetation community and structure (Thomas 1979).

Impacts on the riparian zone change its vegetation and influences faunal habitat both directly and indirectly through changes in microclimate associated with riparian zones (Thomas 1979). Changes in canopy cover, either through clear-cutting, pasture grazing, agricultural activities, urbanization and the introduction of invasive alien species can alter associated characteristics of riparian zones significantly (Meehan 1970; Brown *et al.* 1971). These characteristics include the microclimate created within riparian zones, the terrestrial environment associated with riparian zones as well as water quality (Thomas 1979).

Riparian zones worldwide have been immensely degraded on a large scale (Holmes *et al.* 2008), with the most influential agents of degradation being catchment-scale modifications and invasive alien plants (Holmes *et al.* 2005; Richardson *et al.* 2007). Invasive alien plants are an ever increasing problem within numerous biomes worldwide (Jansson *et al.*2000; Tickner *et al.* 2001; Holmes *et al.* 2005; Richardson *et al.* 2007; Holmes *et al.* 2008). Not only do they often outcompete and eventually eliminate endemic plant species, but they also alter the entire ecosystem, favouring certain species over others, and in many cases the 'other species' are either invasive alien fauna or flora or even both.

Major invaders of riparian zones are mainly trees which use more water than indigenous riparian vegetation, increasing transpiration leading to reduction in flows(Dye and Jarmain 2004), as well as productivity of land, altering ecosystem processes and structures (Tickner *et al.* 2001), and most significantly, threatening biodiversity (Holmes *et al.* 2008). As a result, invasive alien vegetation inherently degrades the quality of riparian vegetation within different riparian zones.

Overall, riparian ecosystems are categorized among the most anthropogenically disturbed environments, as well as having among the longest history of human disturbances (Nilsson and Svedmark 2002). The world's large rivers have been altered to having a regulated water flow regime (Dynesius and Nilsson 1994), resulting in dramatically transformed riparian conditions, both aquatic and terrestrial (Nilsson and

Berggren 2000). Human-induced modifications and changes, such as embanking, clear cutting, channelization, trenching and pollution, has resulted in the detrimental damage of riparian habitats (aquatic and terrestrial) (Nilsson and Svedmark 2002), along with changes in the flow regime, flood contacts (floodplains) and groundwater level. These impacts cause deterioration not only of riparian habitats, but also of the biodiversity of the riparian zones (Petts 1996; Ward 1998). To reduce these threats to the biodiversity and to the natural ecosystem functions, and to favor sustainable use of rivers and riparian zones, restoration is becoming increasingly essential (Naiman *et al.* 1993; Stanford *et al.* 1996; Ward *et al.* 1999).

Throughout the world, riparian zones or corridors only occupy a small proportion of the Mediterranean-climate regions, but irrelative to its size within these regions they are far more significant beyond the area they occupy (Stella *et al.* 2013). Within these regions they are resource-rich tiny "islands" in semi-arid, human dominated landscapes where they function in providing ecosystem services and functioning (Naiman *et al.* 2005). However, Mediterranean riparian ecosystems are extremely vulnerable to the cumulative pressures from land use, stream flow regulation and diversion as well as climate change, and these pressures are ever increasing (Stella *et al.* 2013).

In the CFR, most rivers are currently dammed or being dammed in at least one place, with the result that few now have natural flood regimes as their hydrological regimes have been significantly altered (Holmes *et al.* 2005; Sieben and Reinecke 2008). This has a direct impact on riparian vegetation as well as the functioning of the riparian and aquatic ecosystems. Currently, it is only in the higher reaches, such as the mountain streams, where the vegetation is in a more or less natural state (Davies and Day 1998; Holmes *et al.* 2005).

The mountain streams of a river are dynamic ecosystems that contain many heterogeneous and patchy habitats (Downs *et al.* 2002). The CFR rivers in particular have a significantly high turnover of species among the various catchments (Reinecke *et al.* 2007), hence the concept of 'catchment signatures', which refers to mountain streams and foothill sites within one catchment being more similar to one another than to other mountain streams or foothill sites. This is particularly true for riparian vegetation and macroinvertebrates (Sieben and Reinecke 2008). However, with the impact that human-induced modifications and invasive alien plants are having on riparian ecosystems, this linkage between mountain streams and foothill sites is being significantly altered, reducing the river signatures, especially within the CFR (Richardson *et al.* 1997, Holmes *et al.* 2005).

Although riparian vegetation has been well studied, invertebrates have not. With modification of riparian vegetation there could possibly be an alteration of invertebrate assemblages in these zones, the focus here.

Biological indicators as a conservation tool

Biologists have used one or a small number of species as surrogates for addressing conservation issues (Thomas 1972; Jarvinen 1985; Bibby *et al.* 1992; Caro and O'Doherty 1998). These surrogate species have been employed to indicate the level and extent of anthropogenic impacts or to assist in understanding population changes of other species. Furthermore, surrogate species and species richness are also proactively used to locate areas of high biodiversity (Ricketts *et al.* 1999), with species richness being the surrogate measure of biodiversity in general where it has become a 'common currency' in copious biodiversity sciences (Ricketts *et al.* 1999).

A popular method which is most commonly used is surrogate taxa. Surrogate taxa are a useful tool in conservation biology especially to delineate geographical areas for the conservation of a suite of species (Caro and O'Doherty 1998). The surrogate taxa method also assists in the conservation of their ecological interactions (New 2005).

Surrogate taxa that are predominantly used in the assessment and monitoring of disturbances to ecosystems are referred to as bioindicators (Caro and O'Doherty 1998, Duelli and Obrist 2003). A bioindicator is a species or a group of species that firstly readily relates the abiotic and biotic state of an environment. It also represents the impact of environmental change on a habitat, community or ecosystem, and can indicate diversity of a subset of taxa, or a wholesale diversity, within an area (Samways *et al.* 2010). These various species can then be categorized into three groups which are based on their intended application: environmental indicators, ecological indicators and biodiversity indicators (McGeoch 1998; Niemi and McDonald 2004; Samways *et al.* 2010).

Distinction between these three groups of indicative species is however important. This is due to the categories having different objectives, and subsequently different approaches, methods and necessary conditions that the bioindicator should fulfill, which is dependent on the objective of the study (McGeoch 1998, 2007). They can be distinguished as follows: environmental indicators are used to detect a change in a system, for instance, the change in the environmental state or response to environmental disturbance; ecological indicators demonstrate the effects of environmental change on either biotic or biota systems; biodiversity indicators can reflect the same measure of the diversity of other taxa in a habitat or within a certain area or sets of habitats (McGeoch 1998; Samways *et al.* 2010).

However, in both environmental and ecological bioindication, the objective has involved the identification of species that are both sensitive to environmental quality and which are noticeably responsive to a change in that quality. Species assemblages are commonly used, especially in insect

biodiversity studies, as they relate and produce significant information. The information should include not just the number of species present, but also the abundance and distribution of each species (Samways *et al.* 2010).

In the CFR there are high levels of endemic invertebrates, many being potential bioindicators for environmental change and health (Samways *et al*, 2010; Gerlach *et al.* 2013). This means that numerous arthropod species may have the potential for monitoring the health and quality of riparian zones in the CFR and potentially worldwide. They may also have value as ecological indicators of environmental change in riparian areas of the CFR. Ecological indicators are often used in various types of environments, such as riparian zones where conditions may be too difficult or expensive to measure directly (Gerlach *et al.* 2013).

Using ecological indicators are therefore an essential and recommended tool for once-off or continuous assessments that enables the demonstration of what effect environmental change (e.g. habitat destruction, landscape fragmentation and transformation and climate change) has on biota and/or biotic systems (McGeoch 2007). Making use of suitable species or species assemblages can also be used as a tool for addressing the biodiversity crisis which is at hand (Samways *et al.* 2010). Among the various bioindicators available, many invertebrates are highly suitable once the goals of the project have been well defined (Samways *et al.* 2010). Moreover, it has also been suggested that terrestrial invertebrates are especially effective indicators for many habitats and regions (Kremen *et al.* 1993; McGeoch 2007; Fleishman and Murphy 2009; Bazelet 2011).

Selecting an effective bioindicator is crucial, and several criteria need to be taken into account. To be a successful and effective ecological indicator, the invertebrate species or species group needs to be sensitive to habitat or environmental change, to have a quantifiable response to changes in its environment, as well as to have feasibility parameters (i.e. be abundant in the environment/habitat, easy to capture, habitat specialization, well known biology, representivity for other taxa, occurrence over broad geographical areas and ranges, and possibly having an economic importance) (Pearson 1994; Hilty and Merenlender 2000; New 2005)and lastly taxonomic stability (Pearson 1994; Fleishman and Murphy 2009).

These features can be used interchangeably, and a bioindicator may be chosen with criteria that are suited to the objective of the study and the function that the bioindicator will entail (Kremen *et al.* 1993, Pearson 1994). Insect species are often ideal as bioindicators, owing to their high species richness, large biomass and most importantly their responsiveness to environmental change (Samways *et al.* 2010).

Terrestrial arthropods dominate terrestrial ecosystems where they have been recognized for their importance in global conservation planning (Wilson 1988; Stork 1988). They make up roughly 93% of the total animal biomass in only one hectare of the Amazonian rain forest (Wilson 1987). However, despite their global significance in global conservation planning, relatively little attention has been given to the monitoring of terrestrial arthropods (Dourojeanni 1990; di Castri *et al.* 1992). The spatial and temporal distribution of arthropods spans across ranges that are also occupied by many plant and vertebrate species. However, arthropods generally occupy finer-grained patch sizes than vertebrates, as well as often having narrower geographic distributions, more complex successional and seasonal sequences, and having patch dynamics that yield a more rapid turnover (Wolda 1988; Usher and Jefferson 1991). Hence, the diversity and abundance of terrestrial arthropods provide the conservationist and ecologist with a rich base of information that is useful in the conservation of biodiversity (Pyle *et al.* 1981; Murphy 1992; Pearson and Cassola 1992). This emphasizes the significance of using arthropods as bioindicators.

Kremen *et al.* (1993) also suggest that terrestrial arthropods may be particularly appropriate candidates for ecological indicators. This is due to their significant rapid response to environmental change, both chemical and physical changes (e.g. effects of pesticides, edge effects, landscape fragmentation and transformation) and their high intrinsic growth rate, which allows them to respond faster to habitat alteration than vertebrates, so allowing a more efficient and quick response time to a detected disturbance. (Kremen *et al.* 1993; Nelson and Andersen 1994). Terrestrial insects also occupy a large variety of functional niches, including riparian zones and microhabitats (Kremen *et al.* 1993).

Study organisms

Grasshoppers as bioindicators

Grasshoppers (Orthoptera: Acridoidea) are an important group of herbivorous insects and account for a high percentage of the phytophagous insect biomass occurring above-ground (Odum *et al.* 1962; Gandar 1982). They are major primary consumers and significant generators and transporters of nutrients in the environment (Gandar 1980), and are major players in energy flow dynamics (Samways 1997).

Another aspect that should also be considered, and which is especially pertinent in the conservation context, is that the bioindicator group should show high levels of endemism (Samways 1990). The Acridoidea (grasshoppers) is one of the most conspicuous groups with respect to levels of endemism (Samways 1990).Herefore, in regions where grasshoppers are most abundant they can serve as good ecological indicators as they meet most of the criteria (Kati *et al.* 2004; Sauberer *et al.* 2004; Steck *et al.*

2007; Bazelet and Samways 2011; Matenaar *et al.* 2015). In central Europe grasshopper species have become one of the most important invertebrate groups in conservation and landscape planning owing to their sensitivity to the changes in the environment and in land use intensity (Matenaar *et al.* 2014). With their sensitive response to environmental change (Bazelet and Samways 2011b,c) and their small home range requirements, which is especially true for flightless species, grasshoppers can be effective bioindicators of habitat quality (Bazelet and Samways 2011a, b, c).

Grasshopper assemblages are also good indicators of certain threatened landscapes and habitats, hence they have played significant roles in the conservation of natural areas and habitats (Rentz and Weissman 1981; Devoka and Schmidt 2000; Gebeyehu and Samways 2002). Their abundance levels also provide essential information, with local-level of abundance representing landscape or regional abundance (Kemp *et al.* 1990; Sergeev 1997) and relative abundance can be used as a sensitive indicator of land use and land transformation (Bei-Benko 1970; Samways and Sergeev 1997). Several studies have prompted the use of grasshoppers as ecological indicators (Baldi and Kisbenedek 1997; Kati *et al.* 2004; Steck *et al.* 2007; Saha and Haldar 2009) or as biodiversity indicators (Sauberer *et al.* 2004). Grasshoppers are species rich, abundant and have high endemicity in South Africa, making them ideal ecological and conservation indicators for a variety of habitats both globally and locally within the area (Bazelet 2011). Another feature of grasshopper assemblages in South Africa which makes them favorable as bioindicators is that there is abundance in endemic species and genera (Chambers and Samways 1998). Grasshoppers are also present in relatively large numbers making them easy to sample and they are present most consistently throughout summer and autumn months making them favorable study organisms (Samways 1990; Samways and Moore 1991). However, to date no studies have investigated grasshopper assemblages associated with riparian zones in the CFR or even South Africa as a whole. Furthermore, no study has looked at how anthropogenic disturbances in the CFR, especially along riparian corridors, influence their species turnover and composition.

Numerous studies have investigated how grasshoppers use corridors or ecological networks in fragmented landscapes. In South Africa, studies have primarily focused on grasshopper assemblages within grassland or savanna biomes, with very little done in the CFR (see Matenaar *et al*. 2014, 2015). The focus of these studies explored how grasshoppers can be incorporated into ecological networks as bioindicators to assess habitat quality within these networks, especially within timber plantations (Bazelet and Samways 2011), how they respond to grazing regimes (Gebeyehu and Samways 2003) and their response to restoration efforts (Gebeyehu and Samways 2002). However, there are no data on how grasshopper assemblages respond to human-induced changes along azonal corridors, and whether they could be used as ecological indicators for the quality of azonal corridors within the CFR.

Grasshoppers are one group which can be consistently sampled across all terrain types (Gandar 1982; Samways 1990; Samways and Moore 1991; Stewart 1997), including riparian zones. Making them ideal ecological bioindicator candidates for assessing habitat quality of riparian zones, as well as for determining how anthropogenic disturbances alter species turnover along riparian zones in the CFR.

Grasshoppers as my study group

Grasshoppers are appropriate bioindicators for several regions and biomes (Kati *et al* .2004; Sauberer *et al.* 2004), and, in South Africa, they show strong and sensitive responses to disturbances in their habitat (Kinvig 2006) particularly to management practices such as prescribed burning (Chambers and Samways 1998), grazing (Gebeyehu and Samways 2003) and mowing (Chambers and Samways 1998). In addition they are excellent indicators of land use, being sensitive to plant composition, density and architecture (Samways and Sergeev 1997; Chambers and Samways 1998; Wettstein and Schmidt 1999; Bazelet and Samways 2011a, b, c).

Grasshoppers are very responsive to changed conditions. However, they are also capable of returning quickly after the impacts or disturbances have been alleviated (Samways *et al.* 2010). Grasshoppers are also a practical bioindicator, as managers can be trained to identify them relatively easily in comparison with other insect groups (Samways *et al.* 2010).

Studies to determine the health and quality of riparian zones have been done in the UK and USA. However, all of these studies used butterflies and their Disturbance Susceptibility Scores (DSS) (Nelson and Andersen 1994). Even though CFR butterfly diversity is high, in the fynbos biome, they are underrepresented (Proçhes and Cowling 2006), locally scarce and often very cryptic. This means that in the CFR, grasshoppers are more suited as ecological indicators of environmental change along riparian corridors.

The CFR is particularly rich in Orthoptera endemic species, many being flightless (Matenaar *et al.* 2014), as well as having high overall species richness (Naskrecki and Bazelet 2009). The smaller of the flightless Orthoptera species are well known to be at higher risk of extinction than most winged species, as a result of their poor dispersal capability and specific habitat requirements (Reinhardt *et al.* 2005; Witzenberger and Hochkirch 2008). Specialist, endemic species may thus be good targets for conservation because they should be vulnerable to disturbances.

Objectives and thesis outline

Grasshoppers are the focal organisms, and I aim to determine whether there is a characteristic assemblage associated with the natural riparian zone using the terrestrial zone as a reference site (Chapter 2). I also aim to determine how this assemblage changes in response to agricultural and urban transformation of this zone, and also the impact of invasive alien trees on this assemblage (Chapter 3). Indicator species of good quality natural habitat and of transformation will also be sought (Chapter 3).

The Lourens River in the CFR is the focal study site, where the river will be divided into different land use categories (riparian zones): historic, undisturbed vegetation will be the reference site, against which agricultural, alien tree-invaded, cleared of alien trees, and urban areas will be compared in terms of their grasshopper assemblages. Finally, conservation recommendations will be made (Chapter 4).

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Chapter 2: A grasshopper's perspective of the riparian zone: Lourens River in the Cape Floristic Region, biodiversity hotspot

Abstract

The Cape Floristic Region (CFR) is a global biodiversity hotspot with high levels of endemism across many taxa, including grasshoppers (Orthoptera). Riparian ecosystems are characteristic, diverse and dynamic across the globe. Riparian corridors are a zone of connectivity between the aquatic and terrestrial realms. Although there are various studies on the importance and functionality of riparian zones, little is known about how grasshoppers are associated with these zones, especially in the CFR with its many endemic species from many taxa. Furthermore, no studies have been done on whether or not grasshoppers distinguish between the riparian and terrestrial environment. This study therefore focuses on this aspect and was undertaken along an important river in the CFR (Lourens River), where grasshopper assemblages were compared along the riparian zone and compared to the terrestrial zone away from the river's edge. I show that grasshopper species differentiate between the riparian and terrestrial zones. I also show how CFR grasshoppers are dispersed between the riparian and terrestrial zones.

Introduction

The Cape Floristic Region (CFR) is a global biodiversity hotspot, with high levels of endemic floral and faunal species, including insects (Cowling *et al.* 1989, Linder 2003; Proçhes and Cowling 2006). Insect diversity and endemism within the CFR is high (Johnson 1992; Wright and Samways 1998, Picker and Samways 1996; Proçhes and Cowling 2006; Colville *et al.* 2014), this is also true for Orthoptera (grasshopper) endemicity of the CFR (Naskrecki and Bazelet 2009; Matenaar *et al.* 2014). With this being said many endemic grasshoppers of the CFR are highly specialized on certain plant species and are often flightless (Naskrecki and Bazelet 2009; Matenaar *et al.* 2014).

The CFR is dominated by the Fynbos Biome, with many species, faunal and floral, being highly localized in distribution, and groups of them clustering into 'centers of endemism' (Rebelo and Low 1996; Grant and Samways 2007, 2011). Some of the plant families that characterize the fynbos biome include the Ericaceae, Proteaceae and Restionaceae (Rebelo and Low 1996). Endemic CFR grasshoppers have adapted to the fynbos terrain and vegetation composition and structure, as well as the low nutritional value that are associated with the fynbos vegetation. Such grasshopper-plant specialization is especially seen in the Lentulidae, including species of *Betiscoides*, which are flightless and associated with the Restionaceae (Key 1937), where they are camouflaged by their coloration, small size, and slender body shape (Matenaar *et al*. 2014).

Besides the CFR having its characteristic terrestrial vegetation, it also has a vegetation type known as azonal vegetation. Globally, azonal vegetation is present in many biomes and is not reliant on the climatic conditions of the biome or region (Sieben 2000). Included within this vegetation type is riparian vegetation. Historical, natural riparian vegetation is characteristic in the role it plays in the functioning of riverine ecosystems. It is highly dynamic and diverse, and provides a wide range of ecological niches (Sieben 2000; Sieben and Reinecke 2008; Sieben *et al.* 2009). Furthermore, the riparian zone constitutes a significant ecotone or interface between the terrestrial and aquatic systems (Naiman and Decamps 1990), and embraces sharp environmental gradients, ecological processes and communities (Naiman *et al.* 1993).

The terrestrial vegetation of the CFR is of a different vegetation structure to that of the riparian zone, even though both zones contain endemic and fynbos specific plants. The riparian zone is usually dominated by larger plant structures (trees) than the terrestrial zone (Sieben 2000). In general, the terrestrial zone of the Fynbos Biome is usually composed of plant species that are adapted to nutrient poor soils, having low productivity, and providing little nourishment (high fiber to protein and water ratio) to phytophagous insects (Giliomee 2003). Furthermore, the historic, natural terrestrial environment within the CFR contains more endemic and fynbos specific plant species such as restios and protea plants than the riparian zone. This could result in the creation of two different biotopes due to the difference in vegetation architecture and composition between the riparian and terrestrial zones (Sieben 2000).

Delineating the riparian and terrestrial vegetation from one another is not straight forward, although certain aspects can be used to delineate the width of the riparian zone (see Reinecke 2013), this delineation may differ among rivers and landscapes/topographies (Naiman *et al.* 1993; Reinecke 2013).

Natural riparian corridors are diverse, complex and dynamic biophysical habitats (Naiman *et al.* 1993), and in the larger landscape they have an unusually diverse mosaic of communities and environments (Naiman *et al.* 1993). In addition to riparian corridors encompassing portions of both the aquatic and terrestrial communities (Naiman *et al.* 1993), riparian corridors are also key landscape feature as they have a substantial regulatory control on environmental vitality (Naiman *et al.* 1992). This includes light, temperature and nourishment regulation, and most importantly, they maintain biodiversity through the unusually diverse assortment of habitats, including microhabitats (Naiman and Decamps 1990). However, it is unclear how many faunal species may be present in riparian corridors (Nilsson 1992) as they may use the riparian corridor as a conduit for movement, and therefore the communities that occur within the riparian zone are inadequately known systems (Nilsson 1992). This may be as a result of its ecological complexity and its locality between two major habitat types (aquatic and terrestrial) (Nilsson 1992) i.e. a conduit for movement. Riparian zones are mediators of community movement between these two habitats and it ishereby perceived as a through flow system interplaying between the neighboring terrestrial and aquatic systems as well as along the length of the river (Nilsson 1992; Reinecke 2013).

In short, the riparian zone provides connectivity between the aquatic and terrestrial environment (Naiman *et al.* 1993) in terms of energy flow, matter and organisms (Ward *et al.* 2002). Most importantly, the riparian zone also provides connectivity along the river system. Such landscape connectivity generally enhances population viability for numerous species with many living in well-connected landscapes (Gilpin and Soulé 1986; Noss 1987; Primack 1993; Noss and Cooperrider 1994; Hunter 1996; Meffe and Carroll 1997). This emphasizes the importance of conserving natural functional corridors within the landscape as they are crucial for the enhancement of biodiversity and the maintenance of the natural genetic flux (Bennet 1999; Samways and Pryke 2015).

Little focus has been placed on the relationship between the terrestrial and riparian zones in terms of their arthropod assemblages (Paetzold *et al*. 2005). Although it is known that there is an association between terrestrial arthropods and those in the riparian zone i.e. Odonata (Nelson 2007; Paetzold *et al.* 2008; Capello *et al.* 2012). This is especially true in South Africa and in the CFR. Research elsewhere has focused on faunal associations with the riparian zone and have also shown how certain animal species (Lepidoptera and birds) can be indicative of riparian vegetation quality and health (Nelson and Anderson 1994; Innis *et al.* 2000; Bryce *et al.* 2002; Nelson 2007), however, no research has yet been done in the

CFR on how fully terrestrial insects are using the riparian corridor and whether or not terrestrial insects can be used as bioindicators for riparian vegetation health and quality. As grasshopper species are well represented in the CFR, they have a high level of endemicity and some species are highly specialized to specific fynbos plant species (Matenaar *et al.* 2014), grasshoppers have the potential to be good bioindicators of threatened riparian habitats, especially in view of them having played a significant part in the conservation of natural areas generally (Gandar 1982; Devoka and Schmidt 2000; Gebeyehu and Samways 2002). They have been used extensively as a study organism of landscape quality, as they are generally easily sampled and identified, often have small home ranges, and are influenced by plant architectural traits such as vegetation height, composition and density, making them good focal organisms for bioindication (van Wingerden *et al.* 1991; Pearson 1994; Fleishman and Murphy 2009; Yoshioka *et al.* 2010; Bazelet and Samways 2011a, b; Crous *et al.* 2014).

In the CFR ecological studies have been done on a few endemic grasshoppers, however very little research has focused on how grasshoppers of the CFR respond to the riparian zone. Furthermore, no or very few research investigates their dispersion patterns between the natural riparian and terrestrial zone (and what may be affecting their dispersion patterns). Hereby, I set out to define if grasshoppers perceive a difference between the natural riparian and terrestrial zones.

Sites and methods

Study area and sites

My study was conducted along the Lourens River (-34.027651°S 18.959923°E) in Somerset West, Western Cape Province, South Africa (Figure 2.1). The region has a winter rainfall, and in the mountains there is a mean annual rainfall of 1200 mm, whereas in the lower regions the amount is 915 mm (DWAF 2003). The area is a relatively windy with occasional very strong winds, and wind direction usually being from the south-east or north-west, averaging 4-6.5 m/s. The area is dominated by mountain fynbos, with pockets of afromontane forests in the ravines, Boland granite fynbos, shale Renosterveld and Lourensford alluvium fynbos. Boland granite fynbos is an endangered vegetation type that is characterized by medium-dense to open tree vegetation within tall, dense proteoid shrubland (Mucina and Rutherford 2006). Both shale Renosterveld and Lourensford alluvium fynbos are critically endangered vegetation types (Mucina and Rutherford 2006). Shale Renosterveld has tall, open shrublands and grasslands, whereas Lourensford alluvium fynbos is composed of low to medium-dense shrubland with a short graminoid understory (Mucina and Rutherford 2006).

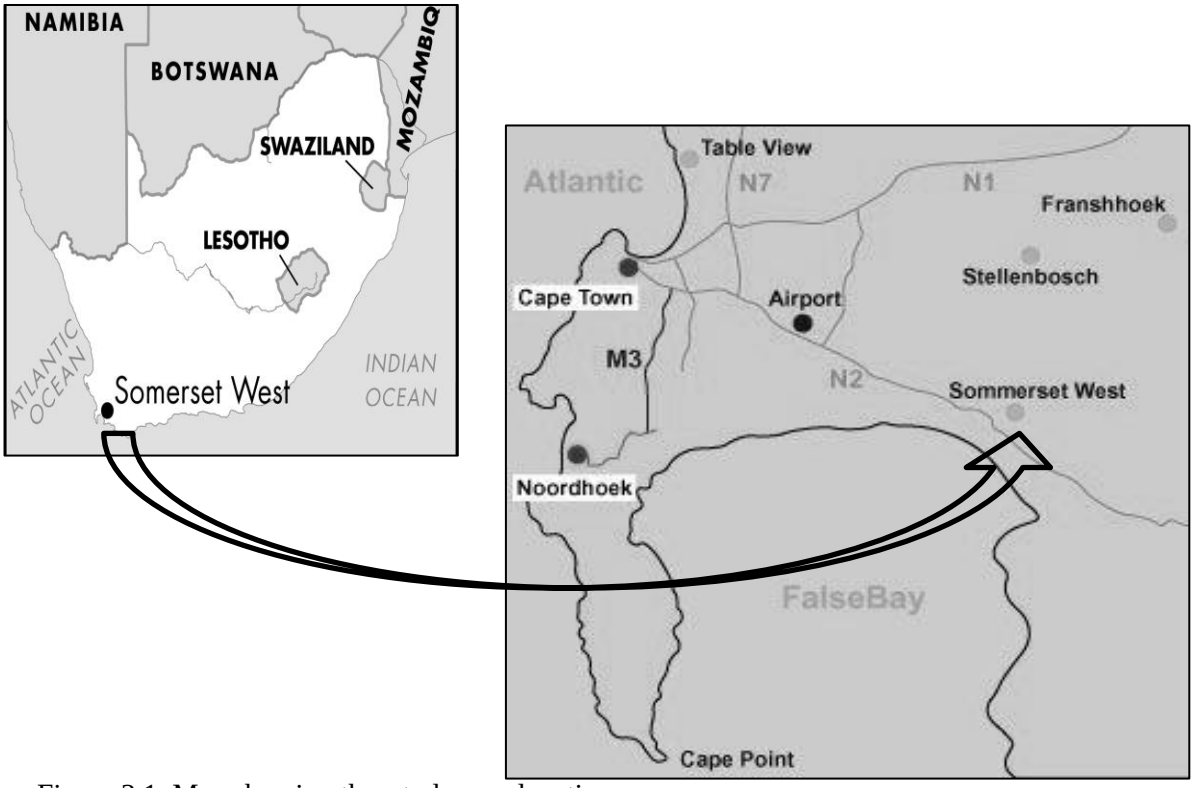


Figure 2.1. Map showing the study area location.

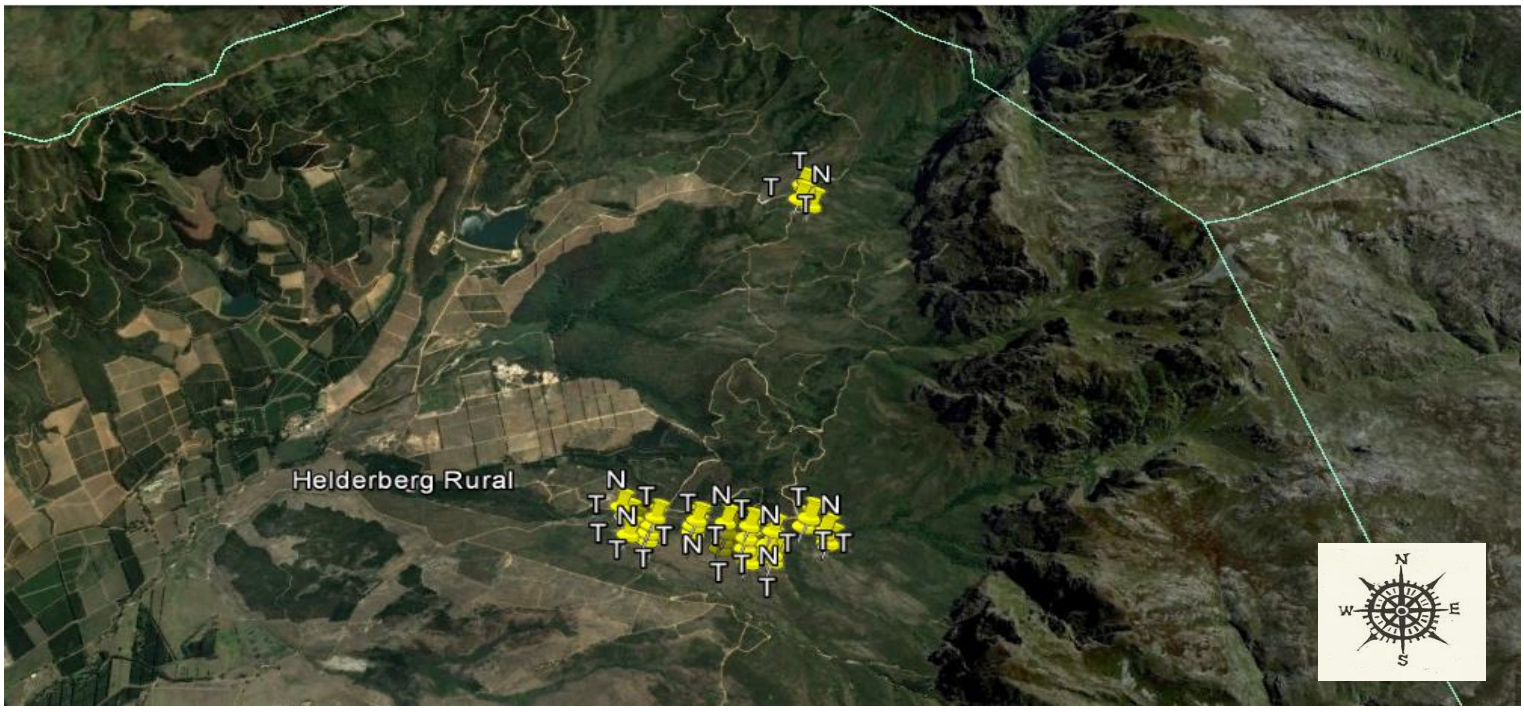


Figure 2.2. Map of the general area of the natural riparian and terrestrial sampling locations (N= natural riparian sites, T= natural terrestrial sites).

The riparian zone included the wet bank zone closest to the river, where the vegetation began, which included bedrock and sand, where water fluctuations are experienced (Figure 2.2). I chose 8 sampling locations along the river over a distance of 2000 m and covering an elevation range of 291-525 m above sea level. Each location was 35 m in width (made up of several transects, see below) and 25 m in length (width referring to the distance perpendicular to the river whereas length refers to the distance parallel to the river) (Figure 2.3). Each of these locations was 200 m apart from the next along the river. Sampling was done on one side of the river. Each location was made up of two natural zones: riparian and terrestrial. In turn, each location was made up of four sites, one being riparian and the other three being terrestrial, with each site parallel to the other i.e. a riparian site on the river's edge and three terrestrial sites at increasing distances from the river (Figure 2.3). The riparian site extended from the river's edge until 35 m away from that edge. There was then an un-sampled gap of 45 m before the parallel first terrestrial site began i.e. 80 m from the river's edge. The 1st terrestrial site was 35 m wide (and 25 m long), and separated from the 2nd terrestrial site by another 65 m gap i.e. the 2nd terrestrial site was 180 m from the river's edge (Figure 2.4). As with the 2nd terrestrial site, there was a gap of 65 m before the start of the 3rd terrestrial site which was also 35 m wide (and 25 m long) i.e. the 3rd terrestrial site was 260 m from the river's edge (Figure 2.4).

Each site had seven sampling units (SUs) in the form of transects, where grasshopper sampling took place. The transects were kept tight and close to one another separated by a 2.5 m gap from the middle of each transect. To summarize the sampling design, each location was made up of four sites with seven SU's each, adding up to 28 transects per location. Each SU (transect) was 5 m wide, and the seven SU's (each 25 m long) were adjacent to each other. This meant that each site covered a sampling area of 875 m^2, each location covered a sampling area of 3500 m^2 (875 m^2 x 4) and the entire study area covered a sampling area of 28 000 m^2 (3500 m^2 x 8).

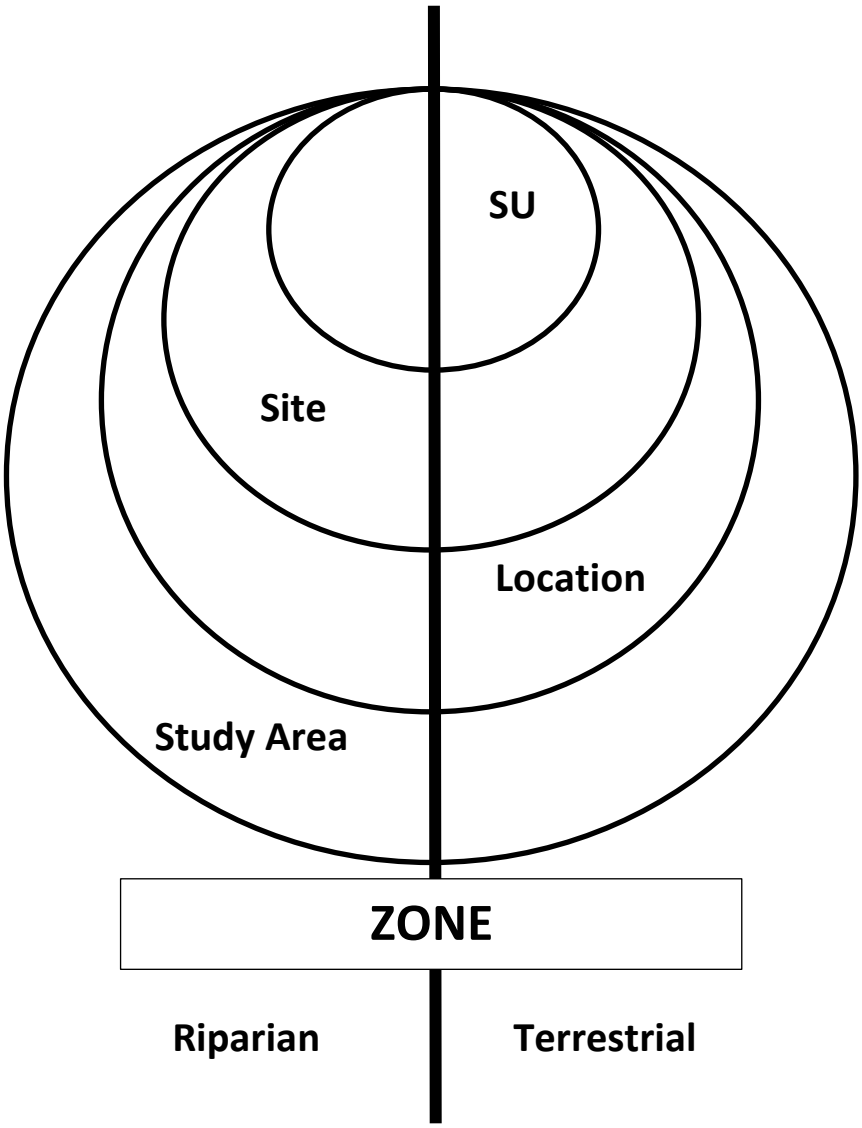


Figure 2.3. Schematic illustration indicating the various spatial scales used in my study.

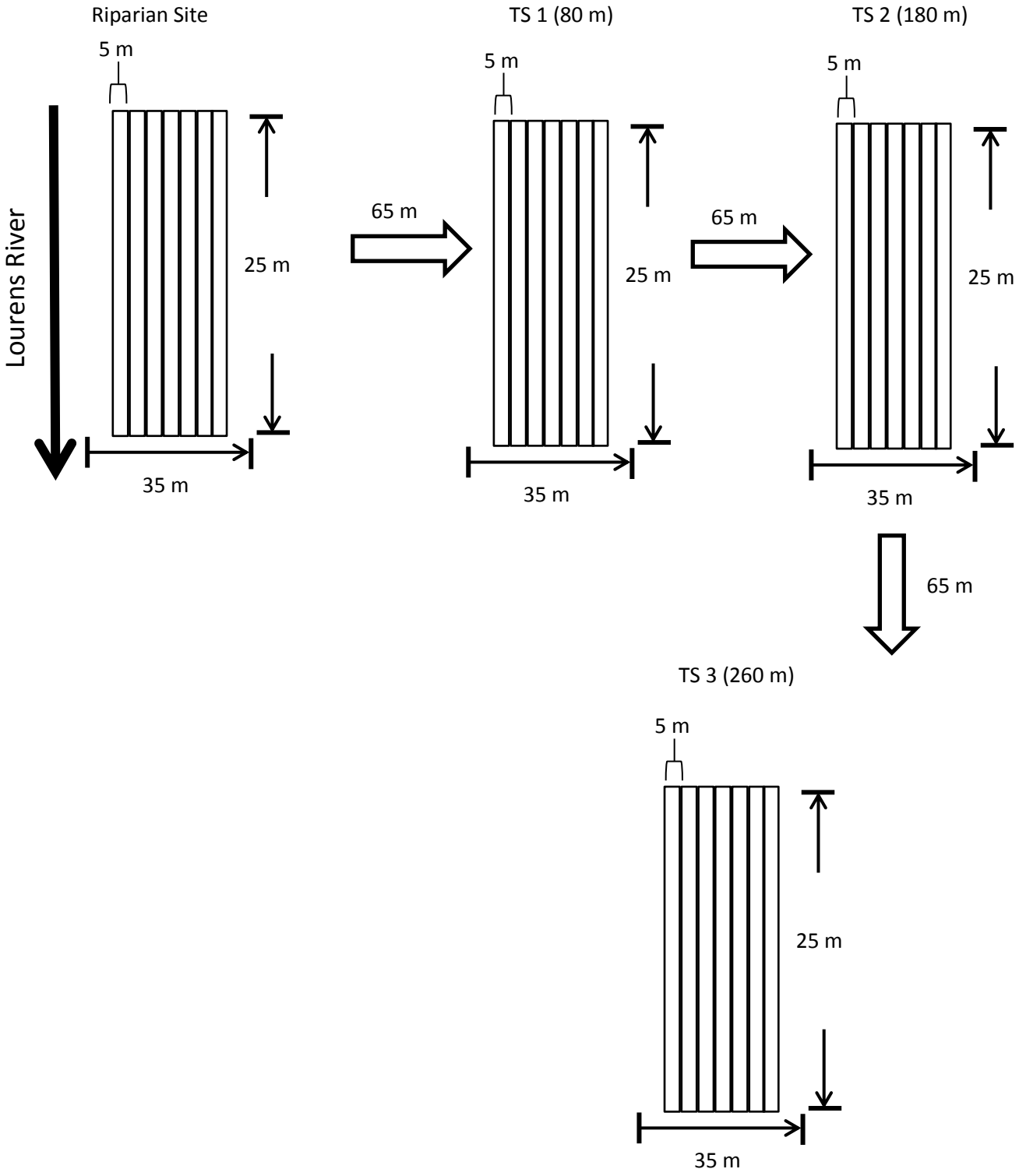


Figure 2.4. Schematic of the layout of the one riparian and three terrestrial sites starting from 80 m from the river terrestrial site 1 (TS1), then terrestrial site 2 (TS2) 180 m from the river and lastly terrestrial site 3 (TS3) 260 m from the river.

Grasshopper sampling

Grasshoppers were sampled on warm, sunny and wind-free days, with a minimum temperature of 20°C, between September 2014 and June 2015 (late spring, throughout summer and early autumn), usually between 9h00 and 17h00. The reason for this is that grasshoppers specifically Acrididae are diurnal and are ectothermic and require heat to operate. Grasshopper sampling took place only once at each site within each location. The aim was to sample all grasshopper individuals in the transects (5 x 25 m) using a combination of sampling methods to ensure that the maximum number of individuals were sampled. Grasshoppers were sampled along each transect of every site, walking the length (25 m) of the SU and then walking back along the same SU, resulting in a sampled length of 50 m (indirectly having a transect of 5 x 50 m). The reason for this double pass was that some grasshoppers are more elusive than others and could only be detected when I returned along the length of the SU (25 m). Only adults were used in analyses to ensure correct identification. Grasshoppers were caught by flushing (Gardiner *et al.* 2002), active searching, especially within the restio stands, observation, and with supplementary sweep netting (Richards and Waloff 1954; Strubinski 1979; Mukerji *et al.* 1981; Evans *et al.* 1983; Young and Young 1998; Foord *et al.* 2002; Fuhlendorf *et al.* 2002; Gardiner *et al.* 2002; 2005; O'Neill *et al.* 2003). I swept along the SU over the vegetation 20 times every 3 m in one direction. This was also repeated on the way back. The net was checked for any grasshopper individuals after every sweep. Sampled individuals were retained with details of date, elevation and GPS coordinates, and placed in a freezer for 2-3 days. Nymphs which were collected accidentally and small individuals were preserved in alcohol. Large-bodied grasshoppers which were expected to rot due to their size were gutted and stuffed with cotton wool. All other grasshoppers were pinned and dried. Specimens were initially sorted to morphospecies, coded, and later identified by taxonomist Dr. C. S. Bazelet, using all relevant references, including Eades *et al.* (2015), Spearman (2013), and Dirsh (1965). The grasshoppers of the CFR have not been studied extensively in recent times (but see Matenaar *et al*. 2014, 2015, Spearman 2013). Therefore, there is a great deal of taxonomic uncertainty even in the case of some common and easy to diagnose species of the CFR (e.g. *Betiscoides* sp.). CS Bazelet identified species to the lowest possible taxonomic level, which in some cases was genus rather than species. As fieldwork progressed individuals of the three most common species were easily recognizable and therefore it was not necessary to collect every individual encountered. If specimens of these species were clearly observed, they were recorded but not collected. Likewise, many individuals were collected, identified and released in the field.

Environmental variables

Vegetation

Vegetation composition, cover and average height were recorded at each SU. Vegetation composition and associated variables were classified into different growth forms: trees, herbaceous plants, shrubs, restio stands, and reeds/sedges/hedges as one, geophytes, ferns, dead biomass litter, rock cover and bare ground cover. Bare ground, dead biomass litter, as well as rock cover, were included into vegetation composition and cover, but not height. This was done as it is known that vegetation architecture (composition, structure, cover and height) significantly influences grasshopper species presence/absence (van Wingerden *et al.* 1991; Crous *et al.* 2014). Vegetation height was measured every 5 m to 6 m with a measuring tool and the average height of each growth form was pooled separately in each SU. The average cover was estimated while walking along the SU (transect). Vegetation cover and average height

was incorporated into all the statistical analysis as a fixed variable. The same was done when determining CFR endemic species richness and abundance, however the presence and absence were also used in many of the statistical analysis. The reason being for this is that the model that would run in the statistical programme R was too big at times and therefore presence and absence were used in numerous occasions especially with the CFR endemic, South African endemic and African widespread grasshoppers. The presence and/or absence of the vegetation growth form were separately pooled for each SU.

Distance from the river's edge and Site

Distance from the river's edge was used to determine and describe how grasshoppers that are located within the CFR are spread between the natural riparian and terrestrial zones and where do grasshoppers tend to be localized i.e. at the river's edge or further away. Thus this would assist in visual determination if there may exist a riparian grasshopper fauna in the CFR. Distance was also used to see where CFR endemic grasshoppers will mainly be found and if they use the riparian corridor/zone. Site was used to determine and illustrate where grasshopper richness and abundance may be more localized i.e the natural riparian site, terrestrial site 1, 2 or 3 and if there is a significant difference between these four sites.

Elevation and GPS coordinates

Elevation and GPS coordinates of SUs 1, 4 and 7 were recorded at each SU using a Polaris Navigation GPS application version 7.92. GPS coordinates were only taken at SUs 1, 4 and 7 because the sites were so tight that there would not be a great difference between the GPS coordinates of each individual SU.

Statistical analyses

The response variables were grasshopper species richness and abundance and their response to distance from the river was tested. Generalized Linear Mixed Models (GLMMs) were calculated using the *lme4* package in R (2015, The R Foundation for Statistical Computing; Bates 2005). GLMMs were calculated using a Laplace approximation and data fitted to a Poisson distribution (Bolker *et al.* 2009). This was done to illustrate the distribution of grasshopper species richness and abundance along the distance of the general study area from the river's edge up until the last SU of the 3rd terrestrial site. Grasshopper species richness and abundance was also tested against vegetation cover and average vegetation height to determine if these variables had a significant influence of richness and abundance. This was done to determine if average vegetation height and cover had a significant influence on grasshoppers in the CFR. In addition individual vegetation cover and average vegetation height was also tested to see if individual growth forms had a significant influence on grasshopper richness and abundance. Further, GLMMs (with Poisson distribution and Laplace approximation) were calculated to determine the overall and CFR endemic grasshopper species richness and abundance and how they are distributed along the distance, from the river's edge up until the last SU of the 3rd terrestrial site. Further models were created to test overall grasshopper richness and abundance, CFR endemic species richness and abundance, as well as the abundance of specific endemic species responses to general vegetation cover and average vegetation height, as well as the height and cover of the various vegetation growth forms in the study area. All models had elevation and day as a random variable. For the GLMMs on CFR endemic grasshopper species richness and abundance, only general vegetation height and cover were used (i.e. bare ground cover, rockiness and dead litter cover, and the presence/absence of the vegetation growth forms) to avoid over dispersion. Only those grasshopper species that had an abundance of more than 10 sampled

grasshoppers were analyzed for their individual abundance data. Pairwise Tukey post-hoc tests were performed on all significant discrete factors using the *multcomp* package in R (Hothorn *et al*. 2008). Further models were created to test if there is a significant difference between the four sites using overall grasshopper richness and abundance as well as CFR endemic grasshopper abundance and richness, South African endemic grasshopper abundance and richness and African widespread grasshopper abundance and richness. GLMM's were used to statistically test this.

Assemblage composition similarities and how it is affected by the fixed factors was calculated using permutational multivariate analysis of variance (PERMANOVA) in Primer 6 version 6.1.13 and Permanova+ version 1.0.3 (Primer-E 2009). F and p values were calculated using 9999 permutations (Anderson 2006). For these analyses, the data were square-root transformed to reduce the weight of common species, and analyses were performed using Bray-Curtis similarity measures (Anderson 2001). PERMANOVAs were constructed for all grasshopper species and then for Cape Floristic Region endemics, South African endemics (only endemic to South Africa) and into African widespread species (present everywhere in Africa, usually generalist species). Species accumulation curves were also constructed along with their relevant Chao2 (±SD) and Jacknife2 values to indicate sampling effort and if it is sufficient.

Results

Grasshopper species richness

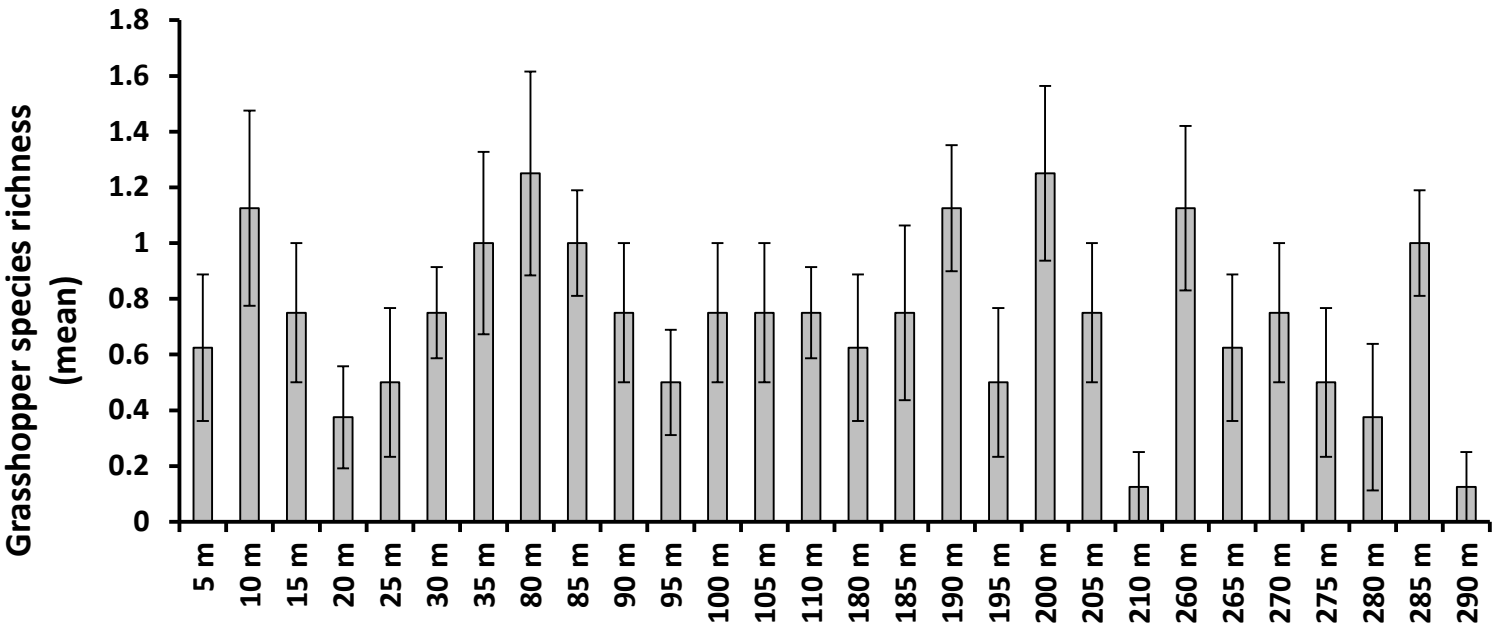
A total of 10 species (221 individuals) belonging to six subfamilies and 2 families were sampled across the entire study (Appendix A). All the environmental variables had no significant effect on grasshopper species richness (distance from river, overall vegetation cover, overall average vegetation height, rockiness, bare ground, dead biomass and then both cover and average height for trees, shrubs, herbs, grasses, restios, ferns and geophytes) with the exception of tree cover (Table 2.1). There was no significant difference found between overall grasshopper species richness and abundance as well as with the Cape Floristic Region endemic grasshopper abundance and richness along the distance from the river's edge (Figure 2.5). Overall grasshopper richness and abundance seems to be spread out randomly along the distance from the river's edge, whereas the Cape Floristic Region endemic grasshopper richness and abundance tend to be more localized further away from the river's edge i.e. into the terrestrial zone from 80 m from the river's edge (Figure 2.5).

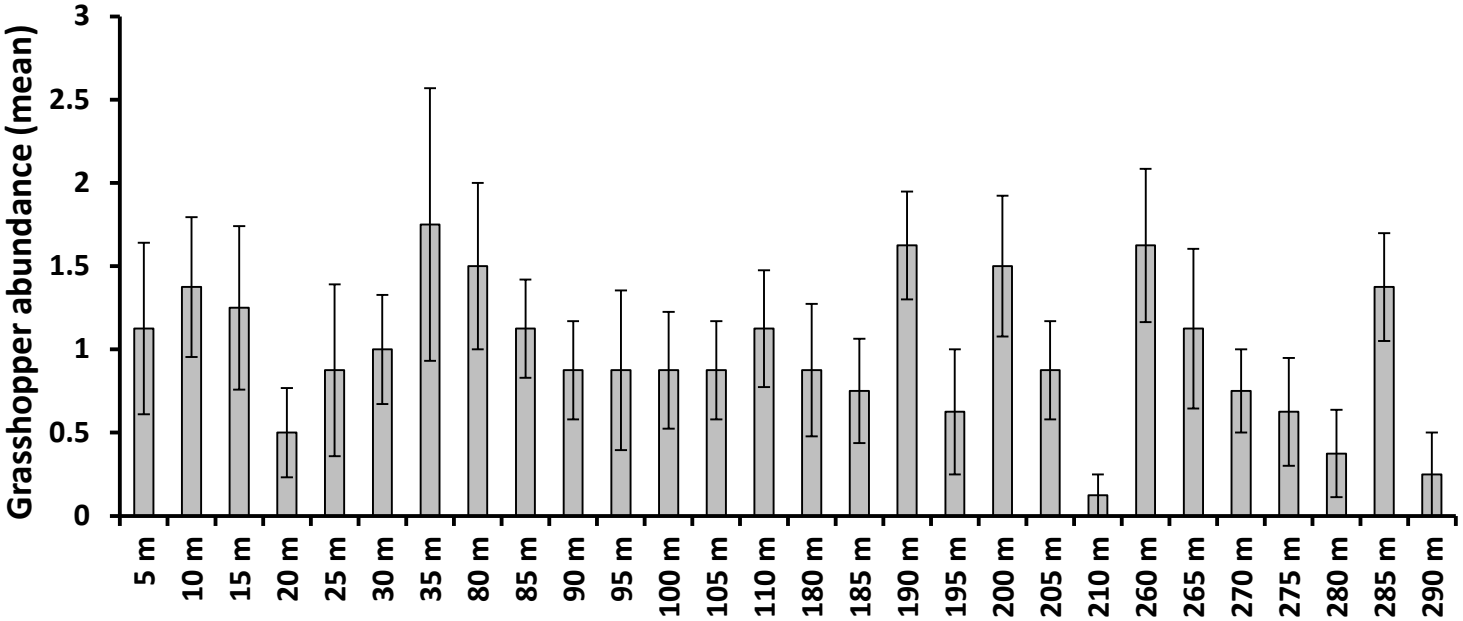
Table 2.1. Generalized Linear Mixed Models were constructed to determine which environmental variables had a significant influence on overall grasshopper species richness as well as models that to calculate the influence of different d vegetation cover and height on overall grasshopper richness.

Environmental variables	Overall grasshopper richness	Species richness with different vegetation cover in the model	Species richness with different vegetation height in the model

Distance	28.79	31.02	29.53
Vegetation cover	0.80	-	0.01
Average height of vegetation	0.08	0.18	-
Rock cover	0.93	1.11	-
Bare ground cover	1.68	2.20	-
Dead biomass cover	0.44	1.31	-
Tree cover	-	5.55*	-
Shrub cover	-	1.35	-
Restio cover	-	0.78	-
Herb cover	-	2.35	-
Grass cover	-	0.08	-
Geophyte cover	-	0.32	-
Fern cover	-	0.19	-
Tree height	-	-	0.08
Shrub Height	-	-	1.27
Restio Height	-	-	0.16
Herb height	-	-	0
Grass height	-	-	0.12
Fern Height	-	-	0.01
Geophyte height	-	-	0.38

Values represent Chi-squared values for differences in the observed and expected results. *($p<0.05$)





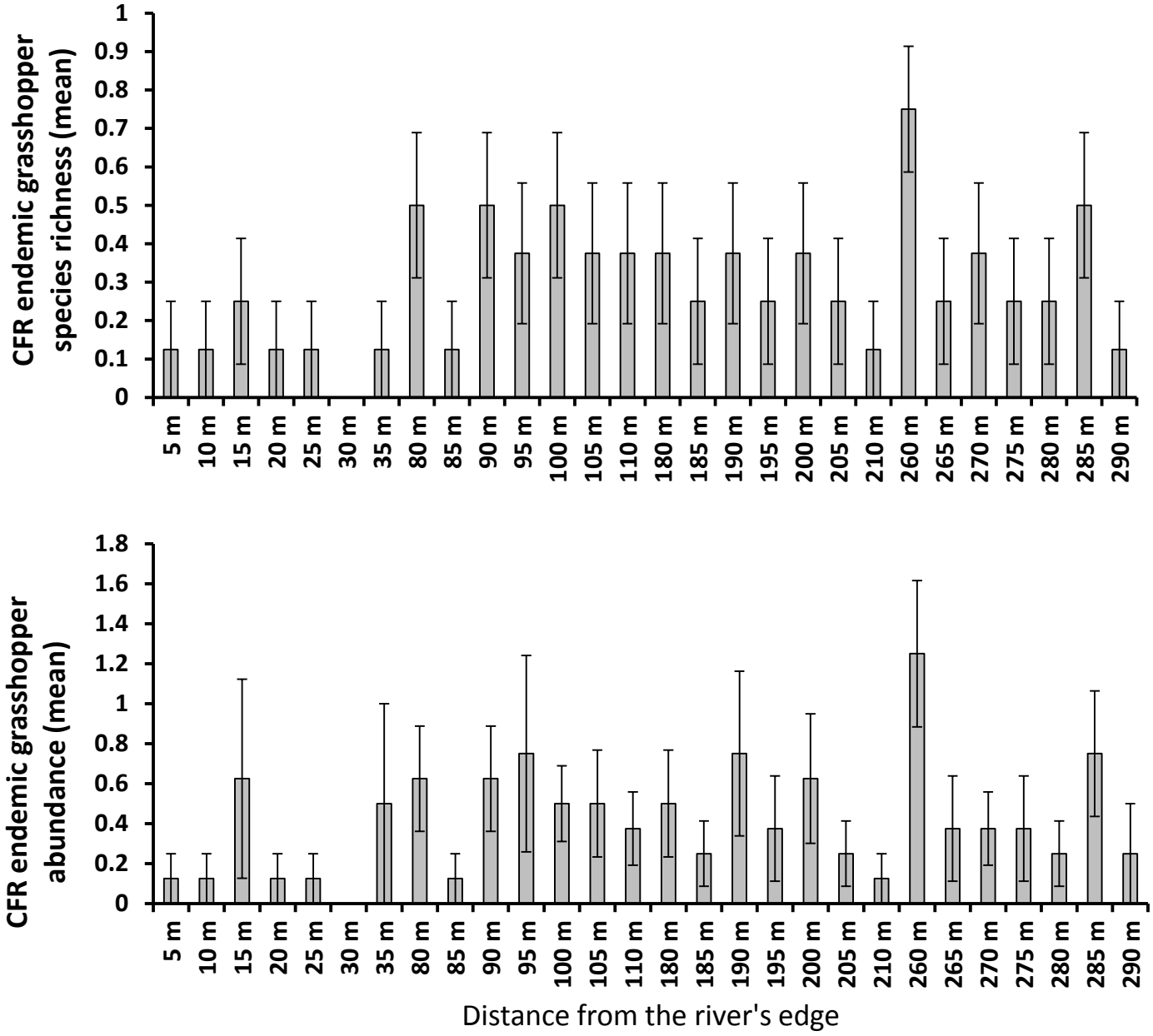


Figure 2.5. Generalized Linear Matrix Models were constructed to illustrate the overall grasshopper species richness and abundance and Cape Floristic Region endemic grasshopper richness and abundance at various distances from the river's edge between the two natural zones.

Grasshopper Abundance

A total abundance of 221 indivual grasshoppers were sampled across the entire study area (Appendix A). all the environmental variables had no significant influence on overall grasshopper abundance (distance from river, vegetation cover, average vegetation height, dead biomass, bare ground, rockiness and then both cover and average height for trees, shrubs, restios, ferns, herbs and geophytes) with the only exception being tree cover and restio height (Table 2.2).

Table 2.2. Generalized Linear Mixed Models were constructed to determine which environmental variables had a significant influence on overall grasshopper abundance as well as models that to calculate the influence of different d vegetation cover and height on overall grasshopper richness.

Environmental variables	Overall grasshopper abundance	Abundance with different vegetation cover in the model	Abundance with differenet vegetation height in the model
Distance	38.51	39.83	39.09
Vegetation cover	1.14	-	0.60
Average height of vegetation	0.20	0.12	-
Rock cover	1.75	1.43	-
Bare ground cover	2.48	1.83	-
Dead biomass cover	0.11	0.52	-
Tree cover	-	5.79*	-
Shrub cover	-	1.23	-
Restio cover	-	0.65	-
Herb cover	-	1.26	-
Grass cover	-	0.02	-
Fern cover	-	0.91	-
Geophyte cover	-	1.07	-
Tree height	-	-	0.10
Shrub Height	-	-	2.30
Restio Height	-	-	4.20*
Herb height	-	-	0
Grass height	-	-	0.30
Fern Height	-	-	0.13

Geophyte height	-	-	0.78

Values represent Chi-squared values representing differences in the observed and expected results.
*($p<0.05$)

A total of 63 grasshoppers were sampled in the riparian zone. A total of 58 grasshoppers were sampled at terrestrial sites 1 (TS1), 51 at terrestrial sites 2 (TS2), and 49 at terrestrial sites 3 (TS3) (Table 2.9). There was no significant difference between overall grasshopper abundance and richness between the four sites (Riparian site, terrestrial site 1, 2 and 3) (Figure 2.6 and 2.7).

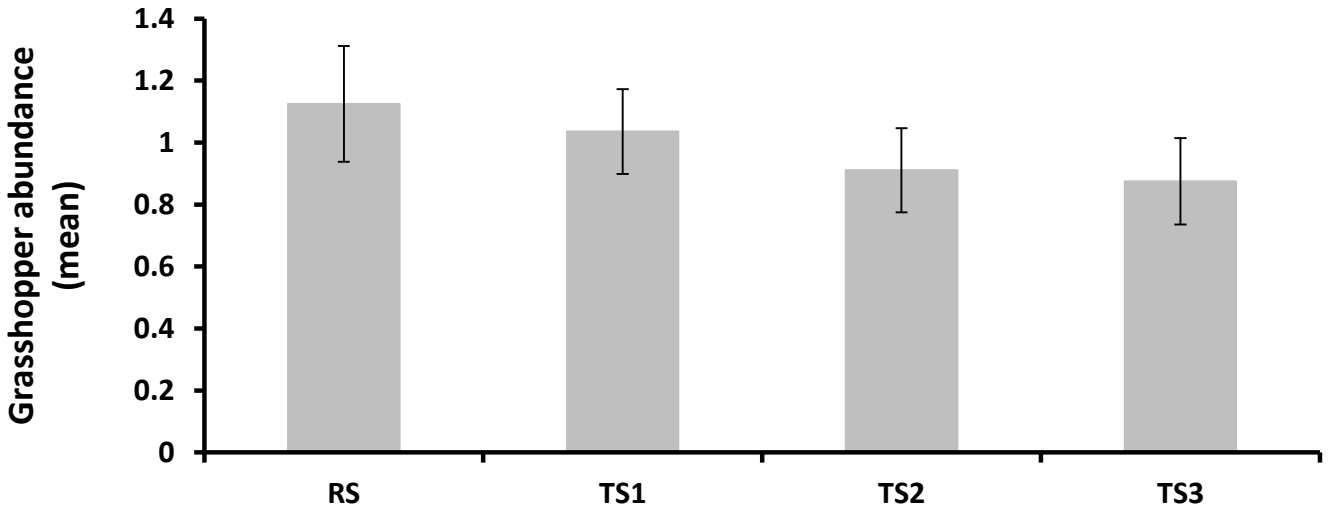


Figure 2.6. Overall mean grasshopper abundance between the four sites of the entire study area (Mean ± 1SE).

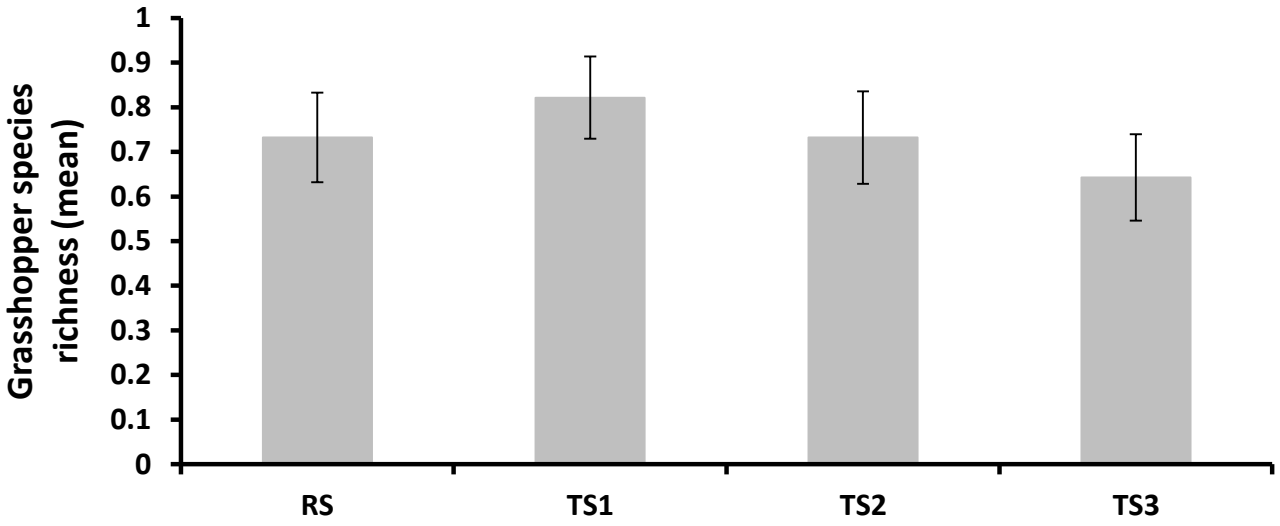


Figure 2.7. Overall grasshopper species richness between the different sites of the study area (Mean ± 1 SE).

Endemic and widespread species richness and abundance

Of the ten species sampled, four are endemic to the CFR, another four are South African endemics, while only two are widespread generalist species (Appendix C). A total of 93 CFR endemic individuals, 108 South African endemic individuals and 20 widespread individuals were sampled (Appendix A).

Of the four CFR endemic species sampled, two are in the Acrididae and two in the Lentulidae (Appendix A). The presence/absence of shrubs, herbs and ferns had a significant influence on both endemic species richness and their abundance (Table 2.3).

Endemic species richness was higher among shrubs and herbaceous plants, and where there were ferns they were absent (Appendix B.1). There were similar patterns for endemic abundance (Appendix B.2).

Table 2.3. Generalized Linear Mixed Models conducted on Cape Floristic Region endemic species richness and abundance in the natural riparian and terrestrial zones.

Environmental variables	Endemic species richness	Endemic species abundance
Distance	18.49	32.35
Vegetation cover	0.10	0.98

Average height of vegetation	0.73	2.38
Rock cover	0.18	2.20
Bare ground cover	0.13	0.66
Dead biomass cover	0.21	0.11
Tree (presence/absence)	3.09	1.94
Shrubs (presence/absence)	4.07*	6.34*
Herb (presence/absence)	6.42*	5.60*
Restio (presence/absence)	0	0.01
Fern (presence/absence)	10.23*	12.37*
Geophyte (presence/absence)	0.03	0.01
Grass (presence/absence)	0.01	0

Values represent Chi-squared values representing differences in the observed and expected results.
*($p<0.05$)

There was no significant difference found between the mean CFR endemic grasshopper abundance and the four sites (Figure 2.8). There was a significant difference found between the mean CFR endemic grasshopper richness between the riparian site and terrestrial site 1 (Figure 2.9).

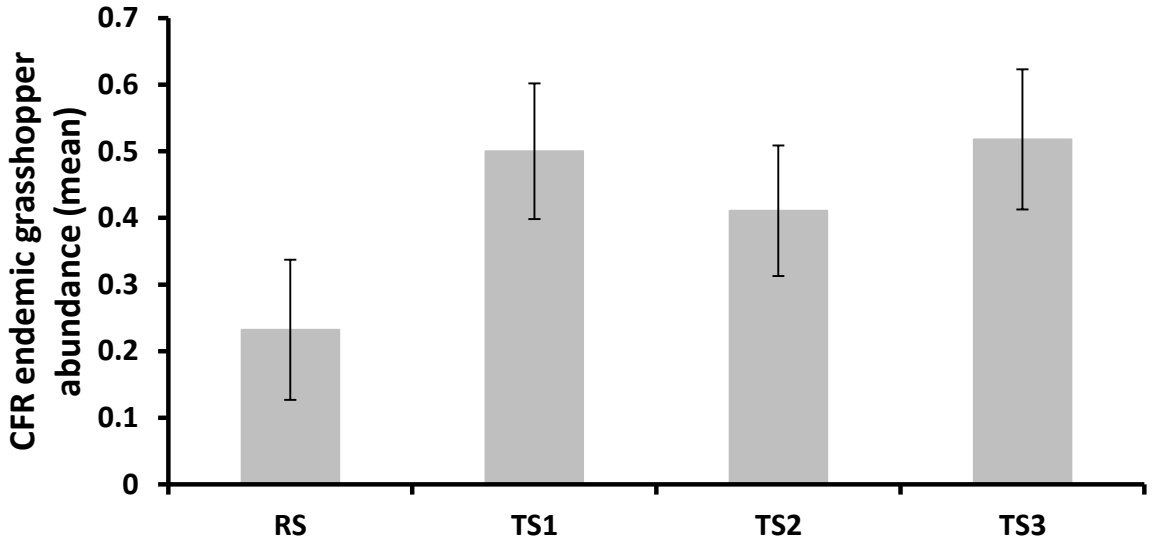


Figure 2.8. CFR endemic grasshopper abundance between the four different sites of the study area (Mean ± 1SE).

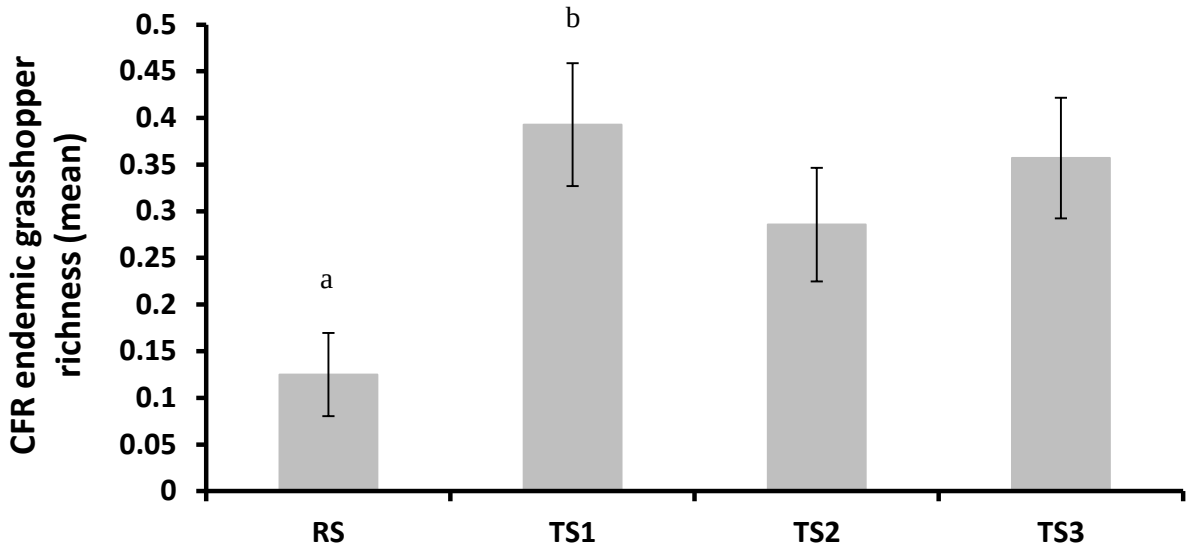


Figure 2.9. Mean CFR endemic grasshopper richness across the difference sites of the study area, the letters represent a significant difference (Mean ± 1SE).

Abundance of individual species along the distance from the river's edge

Only four species were used for individual based statistical analysis, being those where >10 individuals were sampled: a *Betiscoides* sp. (Lentulidae, Lentulinae), *Vitticatantops humeralis* (Acrididae, Catantopinae), *Eyprepocnemis calceata* (Acrididae, Eyprepocnemidinae) and *Acanthacris ruficornis ruficornis* (Acrididae, Cyrtacanthacridinae) (Appendix A).

Betiscoides sp. was the only CFR endemic species that was sampled with >10 individuals (Appendix A). It was influenced by both the presence/absence of shrubs and ferns (Table 2.4). It was abundant in the presence of shrubs and absent in the presence of ferns (Appendix B.3). Its abundance increased from the riparian zone (5 m-35 m) into the terrestrial sites (80 m-290 m) (Figure 2.10). *Betiscoides* sp. was the only CFR endemic species that had an abundance of more than 10 individuals. The genus *Betiscoides* is unique, easy to diagnose and occurs in close association with restio plants (Matenaar *et al*. 2014). All *Betiscoides* species exhibit crypsis and are difficult to detect when situated on restio plants. Therefore, all *Betiscoides* species are necessarily CFR endemics since the vast majority of South African restio species occur in the CFR. At present, *Bestiscoides* consists of three described species which were described in 1923 and 1937. However, the diversity of *Betiscoides* species is clearly far larger than this, and the genus is currently being revised (Matenaar *et al*. in preparation). Furthermore, characters considered diagnostic in the original species descriptions display a great deal of intraspecific variation. Given this current taxonomic uncertainty, CS Bazelet who performed the species identifications, does not currently assign *Betiscoides* specimens to an existing species, as species classifications are likely to change in the near future and published records of *Betiscoides* distribution using the current names will only cause confusion once the taxonomic revision has been completed and new species have been described.

Vitticatantops. humeralis is a South African endemic, which was significantly influenced by distance, i.e. distance from the river's edge but there were no pair wise significance between the distances from the river's edge (Table 2.4). This species was also significantly influenved by the presence/absence of restio plants (Table 2.4). This species was abundant when there were restio plants (Appendix B.3). However, its dispersion pattern from the river's edge to the last SU of the 3rd terrestrial site was not uniform (Figure 2.10).

Eyprepocnemis. calceata, also a South African endemic (Appendix C), was significantly influenced by the presence/absence of trees (Table 2.4), and was abundant where there was trees (Appendix B.3). Furthermore, its distribution from the river's edge showed a peak abundance at the riparian site (5 m-35 m) with a decrease in abundance at 35 m from the river's edge (Figure 2.10). There was no significant difference between the four sites.

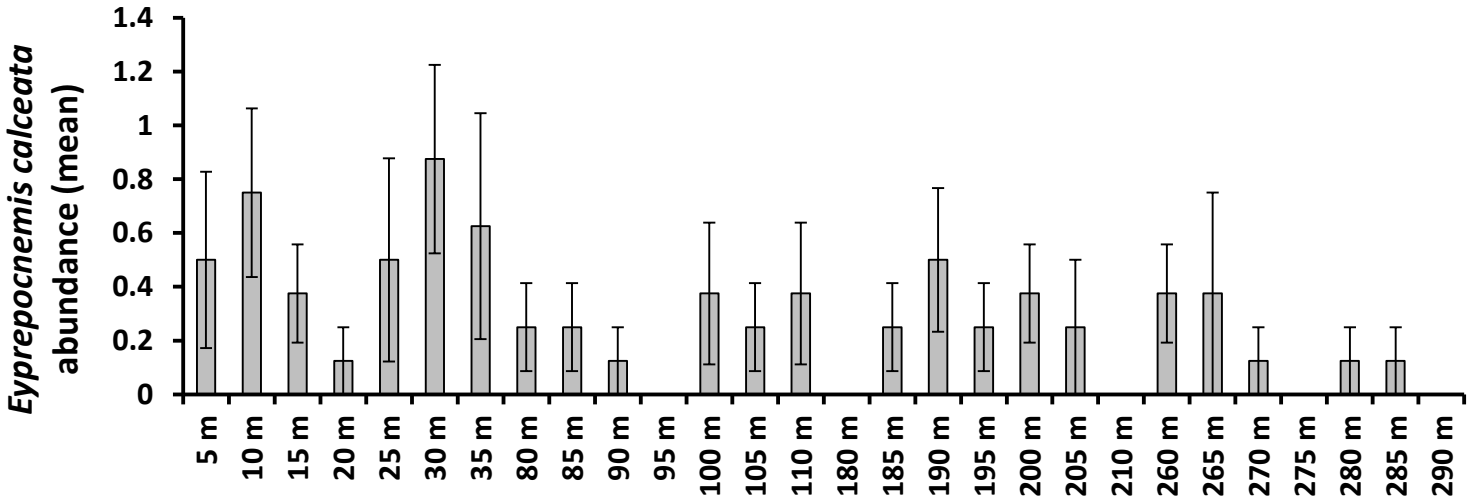
A subspecies of the African widespread species *A. ruficornis ruficornis*, had a strong affiliation with the river's edge, being most abundant 5 m from the river's edge and mostly confined to 5 m-15 m from the river's edge (Figure 2.10). Furthermore, it was less abundant in the terrestrial sites.

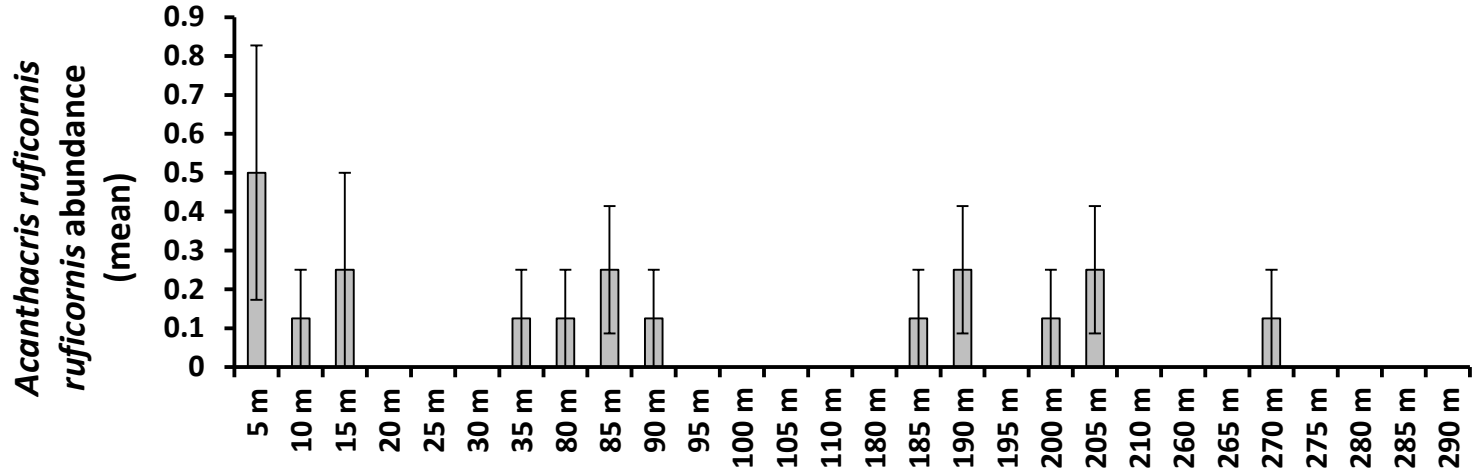
Table 2.4 Generalized Linear Mixed Models on the abundance of selected single species their response to environmental variables.

Environmental variables	*Betiscoides* sp.	*Vitticatantops humeralis*	*Eyprepocnemis calceata*	*Acanthacris ruficornis ruficornis*
Distance	36.87	45.70*	37.01	33.141
Vegetation cover	1.54	0.50	0.03	0
Average height	3.54	1.30	0.43	0.41
Rock cover	2.94	0.34	0	0
Bare ground cover	0.83	0.09	1.83	0
Dead biomass cover	0.40	0.20	1.46	0.26
Tree (presence/absence)	3.22	1.98	4.69*	0.33
Grass (presence/absence)	0.39	0.82	0	0.03
Shrubs (presence/absence)	6.68*	0.13	0.57	0.01
Restio (presence/absence)	0.31	5.04*	0.18	1.86
Herb (presence/absence)	3.32	2.09	0.19	0
Fern	10.39*	0.75	0.64	0.95

(presence/absence)				
Geophyte	0	0.01	0.10	0.61
(presence/absence)				

Values represent Chi-squared values representing differences in the observed and expected results. *($p<0.05$)





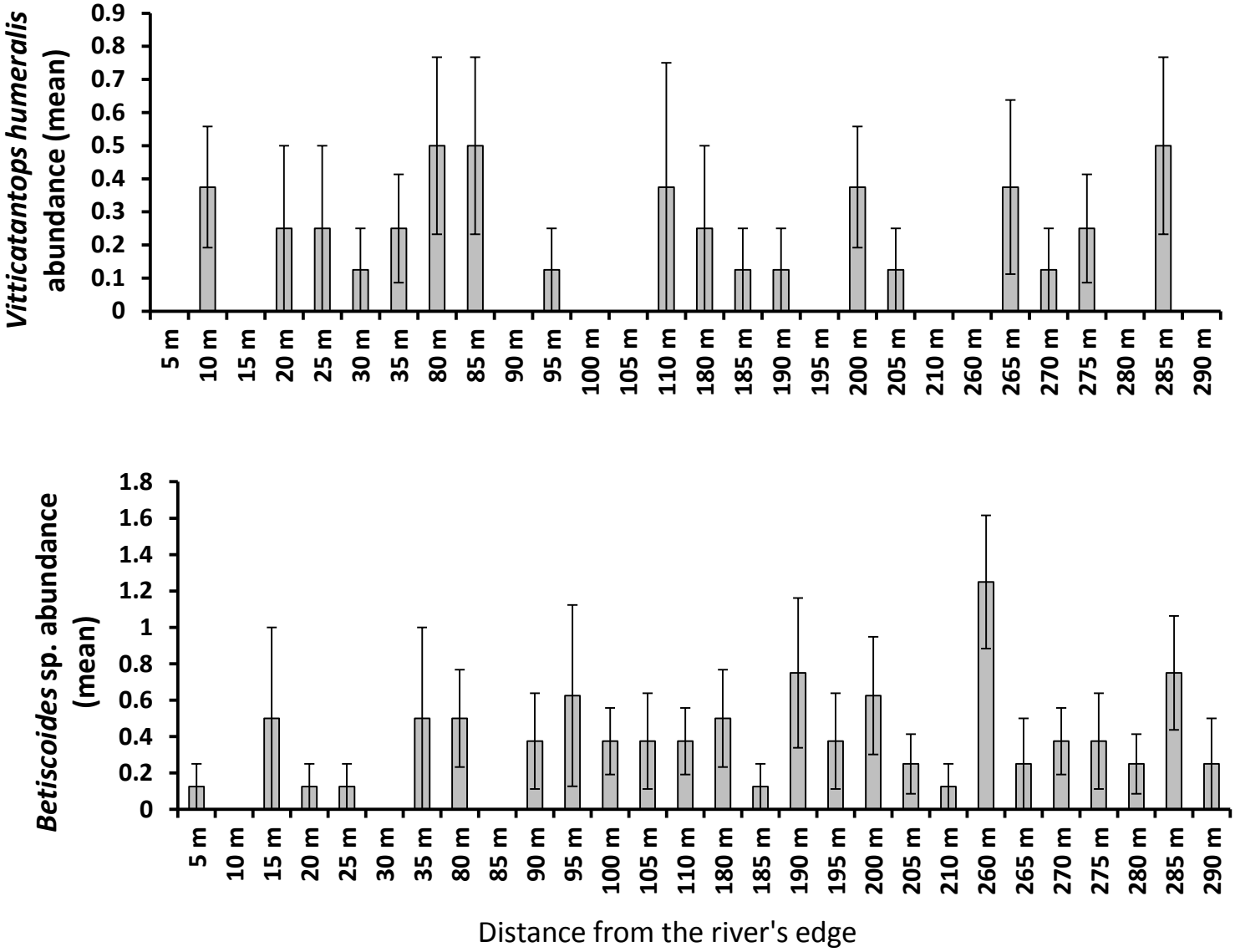


Figure 2.10. Overall single species abundance and distribution from the river's edge to the last SU of the 3rd terrestrial site (Mean ± 1SE).

Overall distribution of general grasshopper species

The macropterous but small-bodied and weakly flighted CFR endemic *Keya capicola* (Acridinae) was sampled only once in TS1 (Table 2.9). The micropterous CFR endemic *Frontifissia laevata* (Catantopinae), was sampled in the riparian zone and within TS1, whereas the other catantopine, Vitticatantops humeralis, a macropterous, strongly flighted, South African endemic, was distributed across both the riparian and terrestrial sites, with highest abundance in TS1 (Table 2.9). *Acanthacris*

ruficornis ruficornis (Cyrtacanthacridinae) was widespread across both riparian and terrestrial zones, although with highest abundance in the riparian zone and TS2 (Table 2.9).

The South African endemic species *Eyprepocnemis calceata* (Eyprepocnemidinae) was well distributed across the riparian and terrestrial zones, but most abundant at the riparian sites (Table 2.9).

The oedipodines *Acrotylus patruelis* (widespread species), *Heteropternis pudica* and *Sphingonotus nigripennis* (both South African endemics) were sampled in both the natural riparian and terrestrial sites of the study area.

Overall assemblage composition

There was a significant difference between the overall grasshopper assemblage composition between the riparian sites and TS1, TS2 and TS3 and between 35 m and 290 m (Table 2.5). There was also a significant difference between overall species composition and high-low shrub height and low-medium restio cover (Table 2.6).

Table 2.5 Permutational multivariate analyses of variance (PERMANOVA) between the differences in grasshopper assemblage composition in riparian sites compared to those in the three terrestrial sites, TS1, TS2, TS3.

	Pseudo-F	t-value	df	p-value
Site	2.476		3	0.01*
Riparian-Terrestrial 1		2.02		0.01*
Riparian-Terrestrial 2		1.95		0.01*
Riparian-Terrestrial 3		2.35		0.001*
Terrestrial 1- Terrestrial 2		0.36		0.92
Terrestrial 1- Terrestrial 3		0.58		0.80
Terrestrial 2- Terrestrial 3		0.90		0.50

Values represent t-values by pairwise comparison. Number of permutations 9999. *($p<0.05$)

Table 2.6. Permutational multivariate analyses of variance (PERMANOVA) between assemblage composition and shrub height and restio cover.

		Pseudo-F	t-value	df	p-value
Shrub height		2.32		2	0.04*
	High-Low		1.65		0.04*
Restio cover	Low-Medium		1.70		0.04*

Values represent t-values by pair wise comparison. Number of permutations 9999. *($p<0.05$)

Cape Floristic Region endemic grasshopper assemblage composition

There was a significant difference in CFR endemic grasshopper species composition between the riparian sites and TS1, TS2 and TS3 (Table 2.7). CFR endemic species composition was also significantly influenced by restio height, with a significant difference among CFR endemic grasshopper species composition at high restio height and low restio height. Hence, high and low restio height had a significant influence on endemic species composition within the study area.

Table 2.7. Permutational multivariate analyses of variance (PERMANOVA) comparison between Cape Floristic Region endemic grasshopper assemblage composition of the riparian and terrestrial sites, TS1, TS2, TS3.

	Pseudo-F	t-value	df	p-value
Site	2.50		3	0.04*
Riparian-Terrestrial 1		2.34		0.01*
Riparian-Terrestrial 2		2.13		0.03*
Riparian-Terrestrial 3		2.28		0.02*
Terrestrial 1- Terrestrial 2		0.65		0.62
Terrestrial 1- Terrestrial 3		0.63		0.64
Terrestrial 2- Terrestrial 3		0.36		0.84

Values represent t-values by pair wise comparison. Number of permutations 9999. *($p<0.05$)

South African endemic and African widespread grashoppers

There was a significant difference found within the South African endemic grasshopper abundance between the riparian site and terrestrial site 2 and 3 (Figure 2.11), no significant difference was found between the South African endemic grasshopper richness (Figure 2.12).

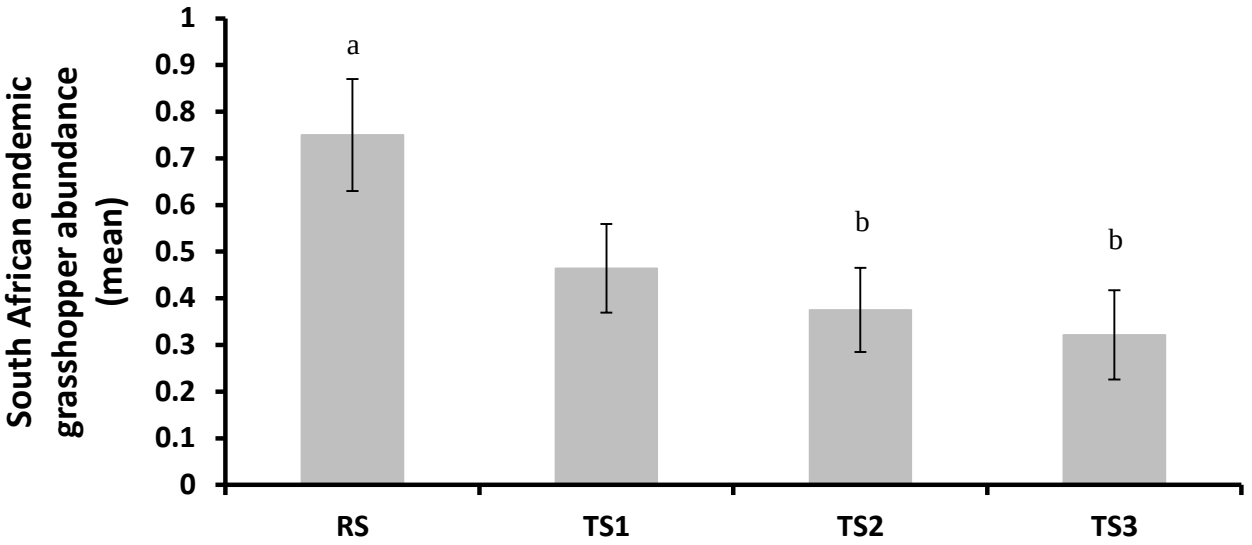


Figure 2.11. Mean South African endemic grasshopper abundance between the four sites of the study area, the letters represents significant differences (Mean ±1 SE).

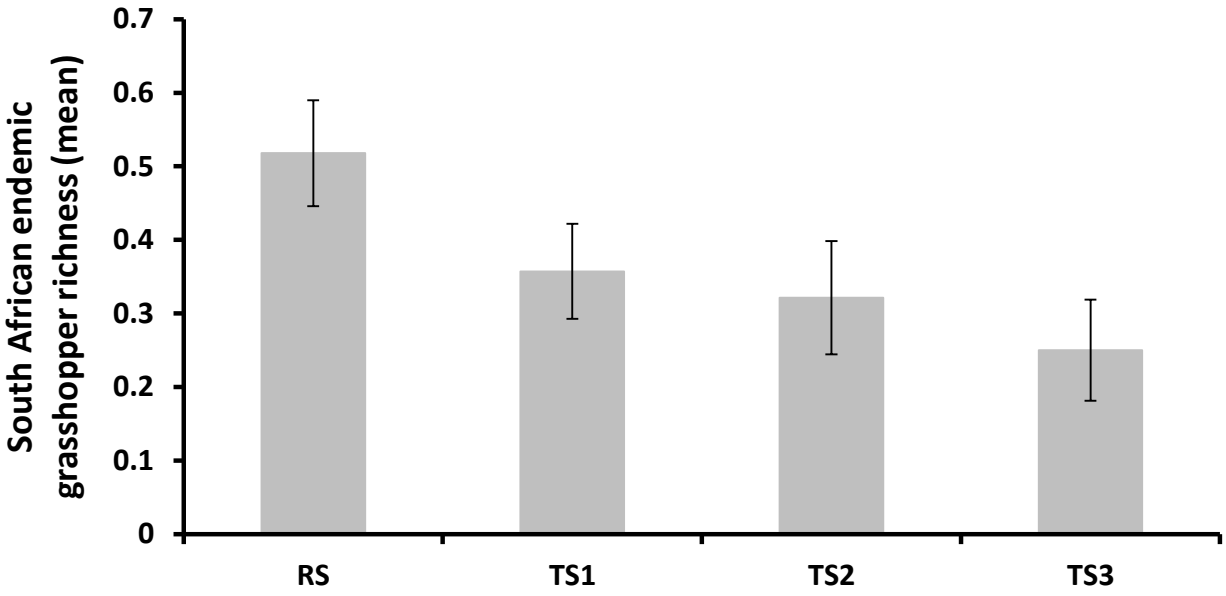


Figure 2.12. Mean South African endemic grasshopper richness between the four sites of the study area (Mean ±1 SE).

There was no significant difference found between African widespread grasshopper abundance and richness between the four different sites (Riparian site, terrestrial site 1, 2 and 3) (Figure 2.13 and 2.14).

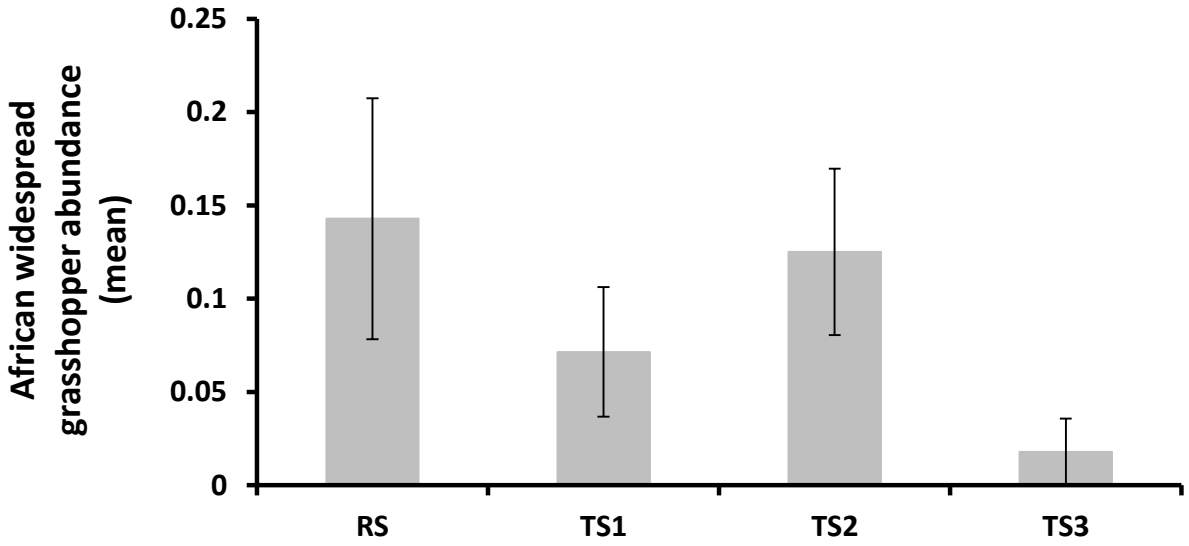


Figure 2.13. Mean African widespread grasshopper abundnace between the four sites of the study area (Mean ±1 SE).

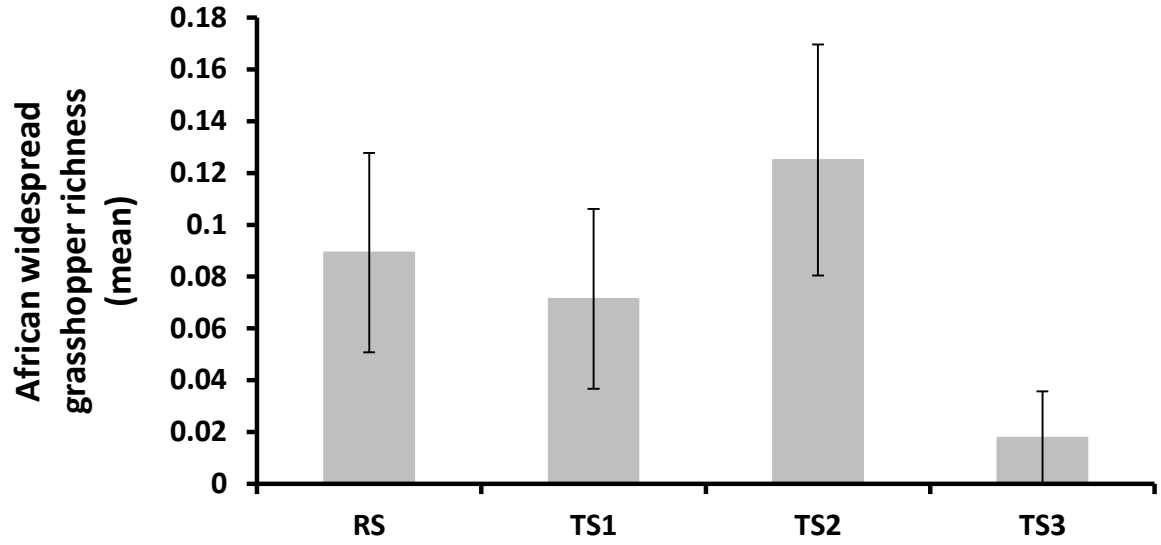


Figure 2.14. Mean African widespread grasshopper richness between the four sites of the study area (Mean ±1 SE).

It is of significant interest that even though *Acrotylus patruelis* is a fairly common, African widespread grasshopper species was only sampled once in TS2 (Table 2.9). *H. pudica* was sampled in the riparian zone and TS1, but in low abundance whereas *S. nigripennis* was sampled only in the riparian zone but was not abundant (Table 2.9). The lentulines *Betiscoides* sp. and *Gymnidium cuneatum* are CFR endemics usually with specific associations with certain fynbos plant species, such as *Betiscoides* and its restio association. Flightless *Betiscoides* sp. was broadly distributed across both the riparian and terrestrial zones (Table 2.9), but with its abundance increasing almost tenfold from the riparian zone to TS1, and then with increasing abundance further from the river, possibly because of its affiliation with restio plants. *G. cuneatum*, is a CFR endemic and was present in low numbers across all sites, but most abundant in TS2 (Table 2.9).

Table 2.9 Grasshopper species and their abundance in the riparian and terrestrial sites, TS1, TS2, and TS3.

Family	Subfamily	Species	Riparian site	TS1	TS2	TS3
Acrididae	Acridinae	*Keya capicola* Uvarov, 1941 [1]	x	1	x	x
	Catantopinae	*Frontifissia laevata* [1,4] Dirsh, 1956	1	2	x	x
		Vitticatantops humeralis (Thunberg, 1815) [2]	10	12	8	10
	Cyrtacanthacridinae	*Acanthacris ruficornis ruficornis* (Fabricius, 1787) [3]	8	4	6	1
	Eyprepocnemidinae	*Eyprepocnemis calceata* (Serville, 1838) [2]	30	13	13	9

	Oedipodinae	*Acrotylus patruelis* (Herrich-Schäffer, 1838) [3]	x	x	1	x
		Heteropternis pudica (Serville, 1838) [2]	1	1	x	x
		Sphingonotus nigripennis (Serville, 1838) [2]	1	x	x	x
Lentulidae	Lentulinae	*Betiscoides* sp.[1, 4]	11	21	22	28
		Gymnidium cuneatum (Rehn, 1944) [1,4]	1	4	1	1

([1]) Cape Floristic Region endemic species; ([2]) South African endemic species; ([3]) Widespread species; ([4]) Flightless species

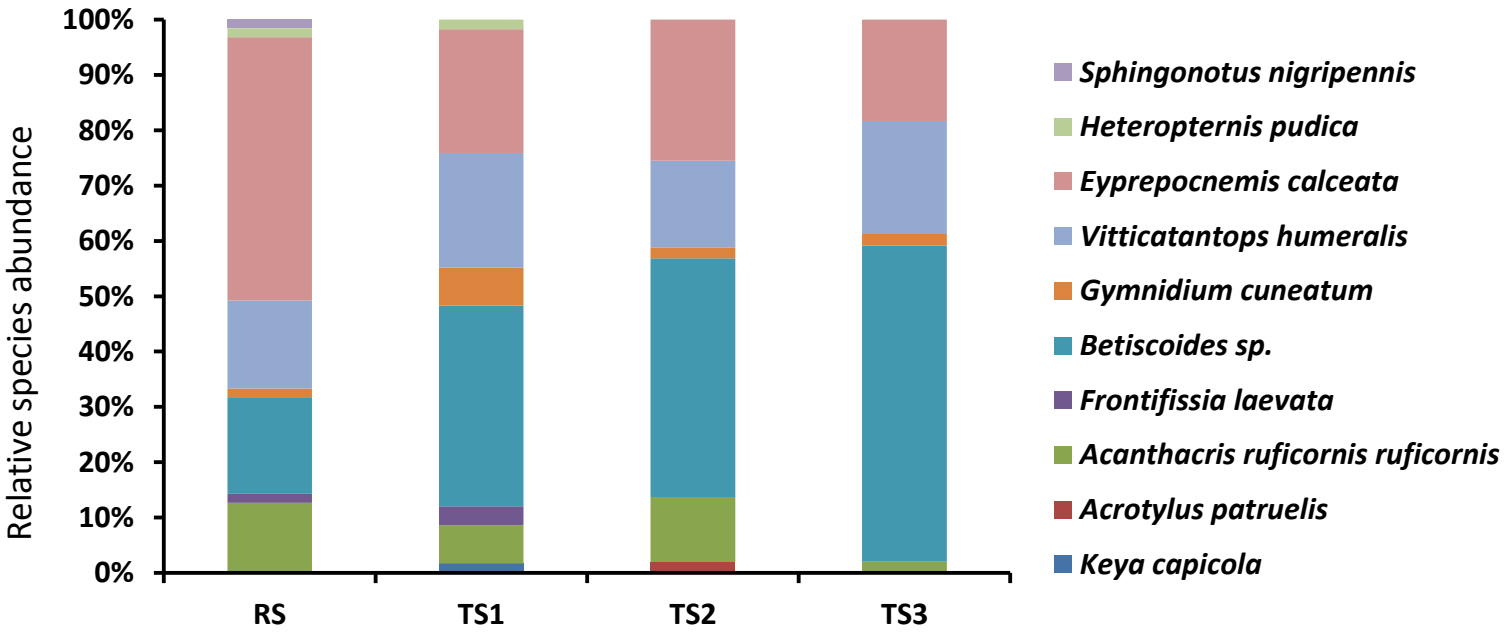


Figure 2.15. Relative abundance of all individual species across the various sites.

In general, the most abundant individual species within the riparian zone was *E. calceata*, whereas *Betiscoides* sp. was the most abundant species at the terrestrial sites, with the highest abundance at TS3 (Figure 2.15). *V. humeralis* had an even abundance across the various sites, where the other South African endemics were not as abundant and decreased at TS2 and TS3 (Figure 2.15).

Low numbers were sampled in this study, but sampling effort was sufficiently done (Table 2.10) (Appendix C).

Table 2.10. Species richness estimators both of the individual zones, riparian and terrestrial (±standard deviation), as well as a combination for both of the zones.

Species Richness estimators			
	SObs	Chao2 (±SD)	Jacknife2
Riparian sites	8	8 (±5.26)	15.789
Terrestrial sites	9	13.5 (±7.2)	13.964
Riparian and terrestrial sites	10	14.5 (±7.2)	14.973

Discussion

Grasshopper species richness and abundance is influenced by the physical structure and composition (e.g. density and cover) of vegetation, making vegetation a key factor determining the presence and local distribution of grasshopper species (Squitier and Capinera 2002). The riparian zone is characterized by containing azonal vegetation, therefore containing both biome specific and non-biome specific plant species. Hence it is an area within the local area with a wide variety of plant species. Natural fynbos vegetation on the other hand is characterized by being relatively shrubby and of a medium average height that consists of typical biome specific elements (fynbos). In the Fynbos biome, the vegetation that is associated with a river is usually a mixture of typical fynbos elements as well as non-fynbos plants that are adapted to the specific ecological conditions around a river (Sieben 2000).

The differences in the vegetation structure between the riparian and the terrestrial zone may possibly influence different grasshopper species, affecting their abundance, richness and distribution over the riparian and terrestrial zones. Consequently, grasshoppers will generally not occur in areas that are lacking their preferred plant hosts, with the physical structure of the vegetation also influencing grasshopper occupancy and dispersion (Squitier and Capinera 2002). This explains the distribution and occupancy of both the South African endemic (SA endemic) and African widespread species (AW species) within and close to the riparian zone, where there may have been a preferred physical vegetation

structure, more so than that was present in the typical fynbos terrestrial zone. Moreover, these two groups of species may not be as well adapted to fynbos vegetation, unlike those species that are endemic to the CFR and have adapted to fynbos specific plant species. Therefore it is more likely that Cape Floristic Region endemic (CFR endemic) grasshoppers will make use of the terrestrial zone (TZ) better than the SA endemic and AW grasshoppers, as I show here. The CFR endemic grasshoppers were mostly in the TZ, with increasing abundance from the RZ to the TZ. This contrasts with the SA endemic grasshoppers which showed the reverse trend in comparison with CFR endemics. In turn, a subspecies of the AW species (*A. ruficornis ruficornis* a strong flier) was dispersed and abundant in both the RZ and terrestrial site 2 (TS2) in particular. The dispersal and abundance of both the SA endemic and CFR endemic species may suggest that there may be niche partitioning, and thus habitat exclusion between these two groups of endemic grasshoppers, resulting in CFR endemics being more confined to the TZ and SA endemics mostly in the RZ.

Garcia-Garcia *et al.* (2008) found that there was a strong association between Orthoptera species and vegetation type, which may be as a result of the different food requirements of the taxonomic groups. Tt can thus be speculated that there may be a strong association between distributional groups of grasshopper species (CFR endemics, SA endemics and AW species) and vegetation types, bearing in mind that the RZ has a greater variety of food resources (widespread of different plant species) for SA endemic and AW species than the TZ, which may require a greater degree of specialization. With that being said, most of the CFR endemic grasshoppers are highly associated with certain fynbos plants (e.g. *Betiscoides* spp. and restio plants) and as a result are highly specialized to the Fynbos biome and its characteristic plant species. Therefore, because of their specialization on fynbos plant species they may be more associated to the natural vegetation type of the TZ of the CFR. This is reinforced by their abundance in the TZ compared to their abundance in the RZ.

The SA endemic grasshoppers seem to have more of an association with the RZ according to their richness and abundance levels between the four sites (Figure 2.11 and 2.12) however this may be in response to the presence of invasive species or trees. According to my findings when considereing indivual species that had an abundance of more than 10 sampled individuals (see Table 2.9 and Figure 2.10) the species that were found to be highly abundant in the RZ included *A. ruficornis ruficornis*, an AW subspecies and *E. calceata*, a SA endemic species. For most grasshopper species, when a grasshopper species is associated with a river, it's most likely because of the vegetation that is associated with the river (e.g. grass or trees). Trees are normally associated with the RZ, and therefore, trees in the RZ may be used in the similar way as woodland trees where they are most likely used as opportunistic perching sites after flight as well as providing good visibility over the landscape (Bazelet and Samways 2014). In addition they may be using the presence of trees in the RZ as an opportunistic food source. This is however dependent on the tree species (Bazelet and Samways 2014).

Among the superfamily Acridoidea, the Acrididae family is actually known to include individual grasshoppers that are associated and involved in aquatic habitats, however they have not evolved toward a completely aquatic lifestyle (e.g. Acrididae: Eyprepocnemidinae) (Amédégnato and Devriese 2008; Bidau 2014). The genera that have had the most evolution in subaquatic adaptations have mainly occurred in the family Acrididae (Amédégnato and Devriese 2008). However, the only known grasshoppers that have an association with the RZ include *Paracinema tricolor tricolor* and tetrigrids (Picker *et al.* 2004; Groenewald *et al.* 2014) which were not sampled in my natural study area. Therefore one would expect to

find these species in the RZ, because both occur in the region and have known associations with water (Picker *et al.* 2004). However, neither one of these species were sampled in the natural RZ, which may be in response to the vegetation architecture and the river qualities itself. It is also considered that the genus *Eyprepocnemis* to be associated with water (Amédégnato and Devries 2008), but it is still unclear if this is also true for *E. calceata* which is widespread in the arid Western Cape, where they are often encountered far from water, even though they were most abundant within the RZ in this study (Bazelet 2015). Nonetheless, very little is known about aquatic Orthoptera in the Afrotropical regions (Amédégnato and Devriese 2008).

Another grasshopper species also tends to be fairly abundant in the RZ, especially at the river's edge. *A. ruficornis ruficornis* is a subspecies of AW grasshopper species and is highly abundant in the RZ especially close to the river's edge at 5 m. *A. ruficornis ruficornis* is known to inhabit invaded and cultivated areas throughout the Cape and are associated to trees where they use them as perching sites (Bazelet and Samways 2014). Therefore it can be speculated that their presence may suggest that some parts of the natural RZ in this study may be invaded, trashed or abundant in trees and appropriate vegetation. As mentioned before, this species also has a relatively low dispersion into the TZ, except in TS2 which may be the result of it being a strong flyer. Furthermore, it may be using the RZ as a refuge as it consists of azonal vegetation and is not biome specific. Thus it can be speculated that this species has an association with the RZ in the CFR as the RZ may provide desired habitat features that are not prominent in the fynbos TZ except at TS2. It is however not uncommon for grasshoppers to utilize more than one habitat type as various Orthoptera species may show some association tendency to different habitat types for instance to avoid predation (Garcia-Garcia *et al.* 2008).

Interestingly enough is the finding that most of the sampled CFR endemic grasshoppers are dispersed and abundant across both the RZ and TZ. Therefore, it agrees with the speculation of Garcia-Garcia *et al.* (2008) that grasshoppers have a tendency to be associated with different habitats. The CFR endemic grasshoppers that were sampled belong to two different families (Acrididae and Lentulidae). *F. laevata* of the family Acrididae is a very interesting find as they are rarely found and may be as a result of their small body size and because they are flightless. This species was only found in the RZ and terrestrial site 1 (TS1), whereas *K. capicola* of the same family was only found in TS1, which may be a chance event as only one was sampled. However, *K. capicola* is capable of flying, but because of its presence in only TS1 it could suggest that they are only found in the TZ and highly associated to only the TZ or that they are very inconspicuous. On the other hand, *F. laevata* of the family Acrididae and *G. cuneatum* of the family Lentulidae, are both flightless species and associated with both the RZ and the TZ. Because they are flightless CFR endemic grasshoppers and highly associated to both the RZ and TZ emphasizes that they make use of these two different habitat types. In addition no solid conclusions can be made on this as there numbers that were sampled was low but however sufficient (Table 2.10 and Appendix C.1). This may also that the natural terrestrial zone and the natural riparian zone and their intermixture of vegetation architecture may be important for CFR endemic grasshoppers, as vegetation is most important for grasshoppers in general.

It is because of this that it is extremely important to maintain these two types of vegetation structures and especially the mix of fynbos and non-fynbos plant species in the RZ. In addition it can also be speculated that there may be a link to the presence of restio stands that are diverse and generally widespread between

the RZ and TZ, thus suggesting that most of the CFR endemic grasshoppers are making use of these restio stands and therefore these stands are also beneficial for CFR endemic grasshopper species.

Betsicoides sp. of the family Lentulidae is a flightless species and is only known to be associated with restio plants and it is uncommon to find them anywhere else. Thus it is of great interest that this CFR endemic grasshopper is dispersed across both the RZ and TZ. Furthermore, this species, according to the findings in this study, is present in high abundance in the presence of both shrub and herb vegetation types but completely absent in the presence of fern plants. This is also noted with the rest of the CFR endemics and the presence of fern plants. The presence of fern plants influences both CFR endemic richness and abundance. Ferns often colonize habitats that have been disturbed either by wind, water, fire or anthropegenic activities, ferns usually colonize recently disturbed and exposed areas such as riverbanks i.e. riparian zone (Mehltreter *et al.* 2010), thus the presence of fern plants indicates that there was a disturbance some time ago and this disturbance may have had a negative impact on the CFR endemic richness and abundance. However in addition to this shade in the RZ may play a role on grasshopper abundance and richness as most grasshoppers tend to prefer open area especially for basking.

Another interesting find is with the Oedipodinae that contains fairly common species that usually occur in numerous environments containing bare ground. However, in this study they were sampled at a very low abundance, suggesting that vegetation was fairly dense and little or no bare ground was available. Therefore it can be speculated that this fairly common and widespread subfamily, because of its low abundance in the natural RZ and TZ, may not be as common in this study area, the Lourens River. This suggests that the fynbos vegetation and its associated insect species, especially the CFR endemic grasshoppers, are highly specialized to their environment.

To conclude, Cape Floristic endemic grasshoppers being biome specific do occur in the riparian zone that is not biome specific. Due to this it emphasizes the importance of the mixture between fynbos and non-fynbos plants in the riparian zone. The maintenance between these two zones is extremely important in order to maintain diversity and connectivity in the landscape especially in a biodiversity hotspot. In addition to this, most CFR endemic grasshopper species are flightless and these patches of fynbos plants in the riparian zone are of high importance for their survival.

In my findings it is clear that there actually exists a riparian grasshopper fauna and may be distincitive if communities are included. On the other hand the presence of the few species in the RZ may just be as a result of some species responding positively to the vegetation in the RZ, and may also be as a result of the prevalence of invasive species or grass in the natural RZ. The species that make up this specific riparian grasshopper fauna do mainly consist of South African endemics and African widespread grasshopper species. This may be correlated to the vegetation architecture of the RZ, which may be more favorable for these species. Therefore, these species, especially the SA endemic and AW grasshopper species may be possible indicators that certain parts of the natural pristine RZ may already be invaded or trashed or on the brink of becoming invaded or trashed. Thus early identification of these species within the natural RZ could possibly be implemented as an ‘alert system’ for management practices to maintain the ‘naturalness’ of RZ. However, the absence of species that should be present in the RZ and the presence of those that like invasion may therefore be more indicative of invasive plant species and and herby have an association with trashed habitats and hereby be less indicative of grasshoppers with the RZ itself.

The conservation of these natural riparian and terrestrial zones is of utmost importance, especially for Cape Floristic endemic grasshopper species as they are generally dispersed among both the riparian and terrestrial zone. According to my findings the conservation of the mixture of biome specific plants and non-biome specific plants in riparian zones should be emphasized as some biome specific Orthoptera species are dependent on this intermixture.

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Chapter 3: Hopping along a river: the impact different land use types along riparian corridors have on Orthoptera in a biodiversity hotspot, CFR.

Abstract

The Cape Floristic Region (CFR) is a biodiversity hotspot and its livelihood is threatened by anthropogenic disturbances. Riparian ecosystems, being uniquely diverse, dynamic and complex, are also threatened by human-induced modifications within the natural riparian corridors. The conversion of riparian corridors to different land use types is occurring at an unparalleled rate resulting in the loss and replacement of endemic and native CFR fauna and flora. The deterioration and conversion of the natural riparian corridors has negative effects on biodiversity, aquatic and terrestrial ecosystems and their connectivity in the landscape. Grasshoppers (Orthoptera: Acridoidea) are good bioindicators for environmental and land use change and habitat deterioration. In the CFR no research has been conducted to determine how riparian grasshoppers are being affected by land use change and if they are viable bioindicators for riparian quality and health. This study therefore focuses on how riparian grasshoppers are affected by various land use types in the different riparian zones along an important river in the CFR (Lourens River), and if certain grasshopper species are viable bioindicators for riparian corridors in the CFR. Grasshopper assemblages were compared along the different riparian zones in the various land uses along the Lourens River. I show that grasshoppers are affected by the different land uses in the riparian zone, and that the level of disturbance also plays a significant role in their abundance and species richness. I also identify certain CFR endemic grasshopper candidates that may be considered for bioindication of riparian vegetation quality and health in the different land uses and the different levels of disturbance.

Introduction

Natural river systems and their associated riparian vegetation zones are pivotal centers for biodiversity (Sabo *et al.* 2005; Paetzold *et al.* 2008), and are one of the most threatened ecosystems worldwide by anthropogenic activities (Paetzold *et al.* 2008). The riparian zone is the area of land adjacent to a river or stream, and it constitutes an interface between terrestrial and aquatic ecosystems. The riparian zone, owing to its dynamic and complex stature, is in many studies the focal point of various disciplines, including biological and physical aspects that relate to biodiversity, conservation, plant invasions, land transformation, restoration and rehabilitation among other aspects (Gregory *et al*. 1991; Blanchard 2008).

The riparian zone is situated between the low and high-water marks as well as extending outwards from the stream bank, and consequently including part of the terrestrial landscape that is influenced by an elevated water table (Gregory *et al.* 1991; Naiman *et al.*1993; Naiman and Decamps 1997). The width of the riparian zone is determined by the hydraulic and topographical nature of the landscape, as rivers are a linear feature in the landscape (Blanchard 2008). The riparian zone will therefore consist of narrow strips of vegetation on low order streams such as those in the mountain slopes or may be seen as large floodplains in more open lowland areas (Blanchard 2008). Riparian zones are also categorized as being an azonal vegetation type, which includes both biome specific and non-biome specific plant species which are not dependent on the regional climatic conditions. In the Cape Floristic Region (CFR) of South Africa, the vegetation in the natural riparian zone differs from that of the natural terrestrial fynbos vegetation, although this does not hamper the dispersion of terrestrial species into the natural riparian

zones (Reinecke *et al.* 2007; Blanchard 2008). Riparian zones are also hotspots in many landscapes as they are often species rich transition zones between the fully hydromorphic and the drier terrestrial zones (Lowrance 1998; McClain *et al.* 2003)

From an ecological view, the role of the riparian zone is as a buffer between the terrestrial and aquatic ecosystems, and is important, as this zone can govern what enters the river system. Therefore the health and quality of the riparian zone is important as it is capable of affecting the way in which ecosystems services are delivered (Blanchard 2008). Furthermore, the riparian zone makes a significant contribution to the nutritional components of the aquatic ecosystem via its allochthonous material inputs (Gregory *et al.* 1991; Blanchard 2008). Therefore riparian vegetation health is just as important as the health of aquatic ecosystems as riparian zones are capable of influencing the health of the water in the river system.

From an anthropogenic point of view, rivers and therefore their associated riparian zones produce numerous benefits for the livelihood of humans. Over millennia, human activities have been associated with riparian zones and as a consequence have often exerted negative impacts to this fragile and complex ecosystem through land use requirements that have resulted in land degradation and habitat loss/fragmentation in general (Richardson *et al.* 2007). Worldwide riparian zones have been degraded on a large scale due to human induced modifications, with major alterations to the ecosystem. Disturbances to riparian zones include urbanization, logging and clear felling for agricultural practices, clearing riparian vegetation in order to eradicate invasive alien vegetation, grazing and timber transportation, resulting in major changes in the distributional patterns of biota (Essl *et al*. 2013).

These disturbances often are a trigger for the proliferation of alien plants, as riparian zones are highly susceptible to being invaded by invasive alien propagules that are transported in the river channel (Richardson *et al.* 2007). This leads to a reduction in the home ranges of native species as well fragmenting them with risk of regional and even global extinction (Sodhi *et al.* 2008; Kuussaari *et al*. 2009; Butchart *et al*. 2010, Barnosky *et al*. 2011). Thus the complementary gains and losses of local and regional faunas and floras are predominantly driven by human activities (Strassburg *et al.* 2012; Essl *et al*. 2013), especially those which are adversely synergistic (Battisti *et al.* 2008). Although when considering the Intermediate Disturbance Hypothesis (IDH) (Connell 1978) some moderate human-induced disturbances can result in a beneficial impact rather than a degrading impact on biodiversity (Kati *et al*. 2012).

Among the different LUTs agricultural practices and the intensification thereof is a major driver of large-scale declines in plant and invertebrate species and are capable of altering and changing vegetation architecture (Robinson and Sutherland 2002). These alterations and changes in the plant community structure can have a major effect on arthropod assemblages, especially grasshoppers (Schaffers *et al*. 2008; Woodcock *et al*. 2009; Emoult *et al*. 2013), which can become impoverished by agricultural intensification (Barker 2004). Yet in contrast, sown margins as a farming practice in agri-environments can increase grasshopper abundance (Marshall *et al.* 2006; Badenhausser and Cordeau 2012). These sown strips can be important especially, along ditches and rivers where grasshopper species richness is enhanced through the provision of favorable wetland habitats (Badenhausser and Cordeau 2012).

Urbanization has a major effect on the ecology of riparian zones (Groffman *et al*. 2003), and is a major cause of local extinction of native species which in turn accelerates the loss of species diversity (McKinney 2008), with faster replacement of native species by non-native ones (McKinney 2006). Yet

invasive species replacing native species can also create a relatively heterogeneous environment through numerous idiosyncratic land uses and plant cultivation choices (Thompson *et al*. 2003; McKinney 2008).

Grasshoppers (Orthoptera: Acridoidea) have a pronounced functional role in food webs, attributed to their ability to recycle ground biomass so producing nutrients for other taxa (Samways 1994). This may be important in riparian zones where they might provide nutrients which are transferred to the aquatic system. Little is known of the role that grasshoppers play in riparian zones and how riparian grasshoppers are affected by anthropogenic disturbances, although it is known that they can be strongly affected by numerous disturbances in other system (Kati *et al*. 2003, 2006). Indeed, grasshoppers are good candidates and bioindicators for illustrating microclimatic and land use change (Samways 1997; Armstrong and van Hensberen 1999), and are sensitive to habitat deterioration and human-induced landscape changes (Steck 2007). Furthermore, their response to environmental degradation can be rapid as they seek more favorable microhabitats (Samways 1994).

It is for this reason that I have chosen grasshoppers to investigate the impact of landscape disturbance along a riparian corridor in the CFR. Little is known about how changes to riparian zones affect grasshoppers and none at all in the CFR, a global biodiversity hotspot rich in endemic species, which are associated to certain fynbos plant species critically important to their survival. Determining the impacts of land uses along riparian corridors would help implement conservation programmes not only to conserve and enhance the quality and health of riparian corridors, but also to ensure the persistence of these vulnerable CFR endemic grasshoppers.

Sites and Methods

Study area and sites

My study was conducted along the Lourens River (-34.027651°S 18.959923°E) in Somerset West, Western Cape Province, South Africa (Figure 3.1). The region has a winter rainfall, and in the mountains there is a mean annual rainfall of 1200 mm, whereas at the lower elevations its 915 mm (DWAF 2003). The area is relatively windy with occasional very strong winds with a wind direction usually from the south-east or north-west, averaging 4-6.5 m/s especially at the higher elevations. The natural vegetation that is somewhat more present within the natural areas and at higher elevations are mainly dominated by mountain fynbos, with pockets of afromontane forests in the river ravines, and other vegetation types: Boland granite fynbos, shale Renosterveld and Lourensford alluvium fynbos. Boland granite fynbos is an endangered vegetation type characterized by medium-dense to open tree vegetation within tall, dense proteoid shrubland (Mucina and Rutherford 2006). Both shale Renosterveld and Lourensford alluvium fynbos are critically endangered vegetation types and are mainly persisting in the natural and higher elevation areas (Mucina and Rutherford 2006). Shale Renosterveld has tall, open shrublands and grasslands, whereas Lourensford alluvium fynbos is composed of low to medium-dense shrubland with a short graminoid understory (Mucina and Rutherford 2006).

The lower reaches of the Lourens River, these include to a degree the cleared and agricultural LUTs but more predominantly the invaded and urbanized LUTs, is to an extant deprived of much natural vegetation (Heydorn and Grindley 1982). The river banks are fringed with a number of different vegetation types such as *Cyperus textilie* (kooigoed), *Juncus kraussii, Typha capensis, Phragmites australis, Elymus*

repens, *Pennisetum clandestinum* and *Paspalum vaginatum*, the trees that encroach on the river bank include a vaying number of *Rhus* species, wattles and garden trees (willows and poplars).

The Lourens River flows through two major Wine estates (Vergelegen and Lourensford Wine Estate) and then through two urban areas namely Somerset West and Strand, where intensive housing and industrial activities taking place and especially along the river itself. The Lourens River is subjected to various anthropogenic activities i.e. agricultural practices (farming with cattle, vinyards and orchards), urbanization (housing, industrial and parks for recreational purposes) and clearing of invasive alien vegetation. In addition to these activites, the visual vegetation structure, architecture and composition differ among the various land use types along the Lourens River. Examples of these changes include exotic plants in and around urbanized areas with the general grass sward height being very low, many areas are invaded with invasive alien tree species and generally natural vegetation is removed for agricultural activities.

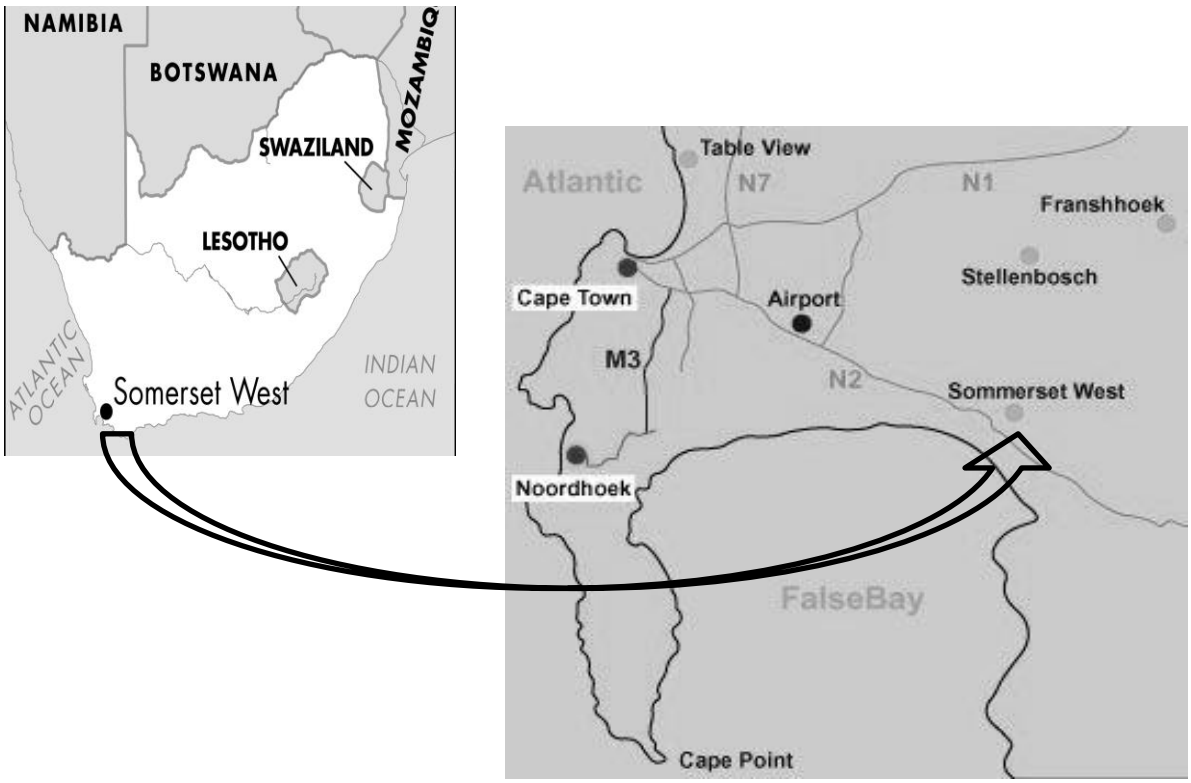

Figure 3.1. Map of the location of the study area.

I sampled five different land use types along the riparian zone of the Lourens River. These land use types along the riparian zone are categorized into five separate land use categories. These categories include the natural riparian zone (reference site), cleared riparian zone, agriculture riparian zone, alien-tree invaded riparian zone and urban riparian zone. The cleared riparian zone consists of a riparian area that had been cleared of invasive alien trees over a number of years. Agricultural activities i.e. vineyards and orchards are generally found 50-70 m away from the river bank and in many instances separated by gravel roads.

The vegetation between the river bank and agricultural land is semi-natural. The natural, agricultural, cleared and invaded riparian zones are located on both Vergelegen and Lourensford wine estates in Somerset West. These two farms were opposite one another along the Lourens River.

Across the study area the different riparian zones did not offer the same number of sampling sites, leading to the natural riparian area having eight sampling sites, the agricultural riparian zone (vineyards and orchards) consisting of 20 sampling sites, the invaded riparian zone of 19 sampling sites, the cleared riparian zone of 10 sampling sites, and the urban riparian zone (parks, houses and main roads) of 20 sampling sites.

This meant that in total there were 77 sampling sites along the riparian corridor of the river and across the different riparian zones, over a distance of 17 325 m and covering an elevation range of 10 – 435 m above sea level (Figure 3.3). Each site within every riparian zone was 35 m wide (made up of several transects, see below) and 25 m in length (width refers to the distance away from the river's edge whereas length refers to the distance along the river). Each site in the different riparian zones included the wet bank zone closest to the river, where the vegetation began, and included bedrock and sand, which experiences water fluctuations. Each location within every riparian zone was 200 m apart from the next along the river in that specific riparian zone. Sampling was done on both sides of the river, which was nonetheless dependent on the specific riparian zone and the availability of the space in the riparian zone. Each site within the different riparian zones of each LUT had seven sampling units (SU's) each, meaning that the riparian sites extended from the river's edge until 35 m away from that edge. Each site had seven sampling units (SUs) in the form of transects, where grasshopper sampling took place (Figure 3.4). To summarize the sampling design, the different riparian zones had their designated amount of sites, where each site was made up of seven SU's each. In summary, the natural riparian zone was made up of seven transects per site and had eight sites, thus 56 transects in the entire natural riparian zone. The agricultural riparian zone consisted of seven transects per site and had 20 sites, thus 140 transects along the agricultural riparian zone. The urbanized riparian zone consisted of seven transects per site and had 20 sites, thus 140 transects along the urban riparian zone. The cleared riparian zone consisted of seven transects per site and had 10 sites thus 70 transects along the cleared riparian zone. The invaded riparian zone consisted of seven transects per site and had 19 sites thus 133 transects along the invaded riparian zone.

Each SU (transect) was 5 m wide, and the seven SU's (each 25 m long) were adjacent to each other. This meant that each site covered a sampling area of 875 m^2 and the entire study area covered a sampling area of 67 375 m^2.

Figure 3.2. Above is the natural riparian area, top left is the agricultural riparian area, top right is the cleared riparian area, bottom left is the invaded riparian area and bottom right is the urban riparian area.

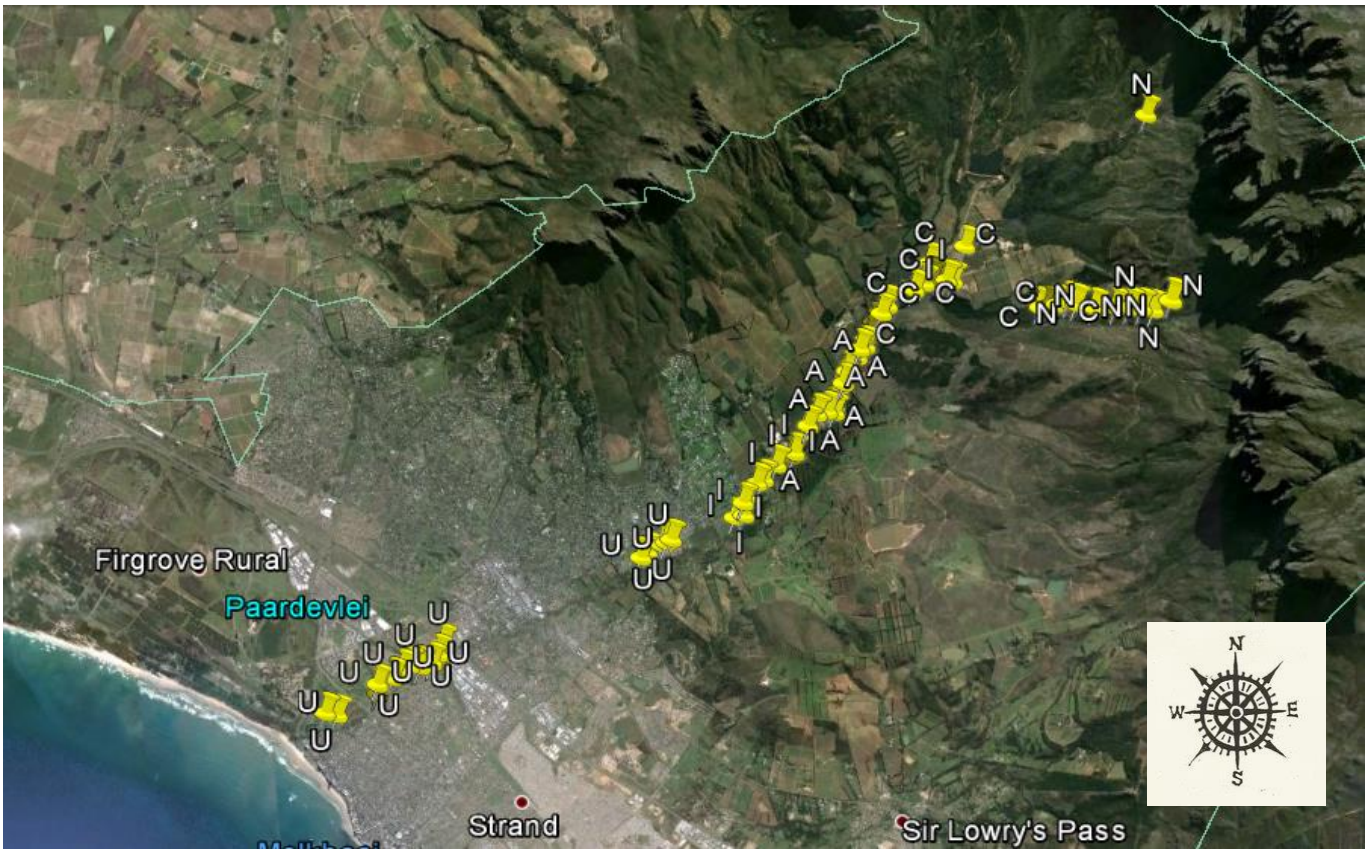

Figure 3.3. Map of the general layout along the Lourens River (N= natural riparian area, A= agricultural riparian area; C= cleared riparian area; I= invaded riparian area; U= Urban riparian area).

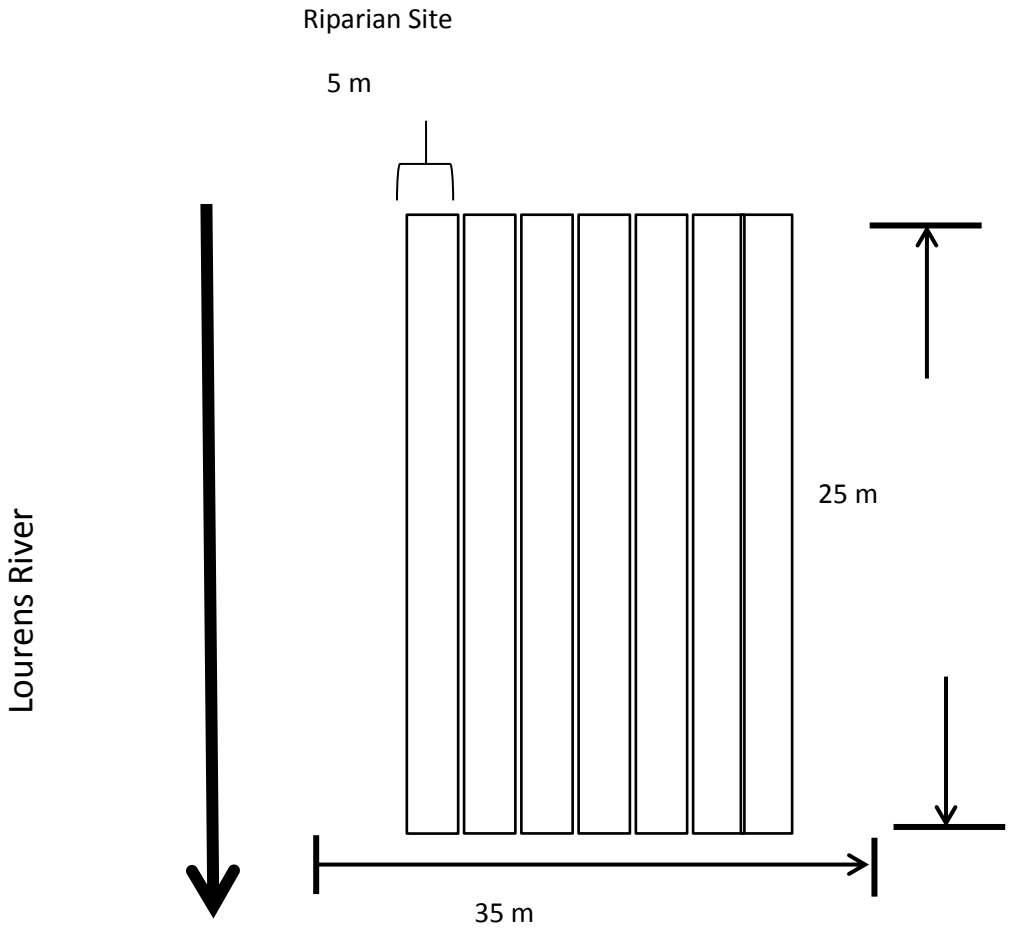

Figure 3.4. Schematic of the layout of each riparian site within the different land uses

Grasshopper sampling

Grasshoppers were sampled on warm, sunny and wind-free days, with a minimum temperature of 20°C, between September 2014 and June 2015 (late spring, throughout summer and early winter), usually between 9h00 and 17h00. The reason for this is that grasshoppers specifically Acrididae are diurnal and are ectothermic and require heat to operate. Grasshoppers were sampled twice in each riparian zone at two different periods. The first sampling season took place between late September 2014 to late December 2014 and again from January 2015 to early June 2015. The aim was to sample all grasshopper individuals in the all transects using a combination of sampling methods to ensure that the maximum number of individuals were sampled. Grasshoppers were sampled along each transect of every site at every riparian zone land use category, walking the length (25 m) of the SU (transect) and up again the same SU, resulting in a sampled length of 50 m. The reason for this double pass was that most grasshoppers are more elusive than others and only jumped away when I returned along the length of the SU (25 m). Only adults were used in analyses to ensure correct identification. Grasshoppers were caught by flushing (Gardiner et al. 2002), active searching, especially within the restio stands, observation, and

with supplementary sweep netting (Richards and Waloff 1954; Strubinski 1979; Mukerji *et al.* 1981; Evans *et al.* 1983; Young and Young 1998; Foord *et al.* 2002; Fuhlendorf *et al.* 2002; Gardiner *et al.* 2002; 2005; O'Neill *et al.* 2003). I swept along the SU over the vegetation 20 times every 3 m in one direction. This was repeated on the way back. The net was checked for any grasshopper individuals after every sweep. Sampled individuals were retained with details of date, elevation and GPS coordinates, and placed in a freezer for 2-3 days. Nymphs which were collected accidentally and small individuals were preserved in alcohol. Large-bodied grasshoppers which were expected to rot due to their size were gutted and stuffed with cotton wool. All other grasshoppers were pinned and dried. Specimens were initially sorted to morphospecies, coded, and later identified by taxonomist Dr. C. S. Bazelet using all relevant literature, including Eades *et al.* (2015), Spearman (2013), and Dirsh (1965). As fieldwork progressed, Individuals of the three most common species were easily recognizable and therefore it was not necessary to collect every individual encountered. If specimens of these species were clearly observed, they were recorded but not collected. Likewise, many individuals were collected, identified and released in the field. Grasshoppers were pooled for every SU, site and land use category.

Environmental variables

Vegetation

Vegetation composition, cover and average height was taken at every SU of every site making use of a measuring tool. Vegetation composition and associated variables were classified into different growth forms: trees, herbaceous plants, shrubs, restio stands, and reeds/sedges/hedges as one, geophytes, ferns, dead biomass litter, rock cover and bare ground cover. Bare ground, dead biomass litter, as well as rock cover, were included into vegetation composition and cover, but not height. This was done as it is known that vegetation architecture (composition, structure, cover and height) significantly influences grasshopper species presence/absence (van Wingerden *et al.* 1991; Crous *et al.* 2014). Vegetation composition was recorded along every SU of every site at either every 5 m or 6 whilst walking along the transects, the same was done with vegetation cover. Average vegetation height was taken with a measuring tool and each growth form was measured, these measurements for each of the growth forms in every SU were pooled for each individual growth form giving an average height of the vegetation composition in the SU.

Elevation and GPS coordinates

Elevation and GPS coordinates of SUs 1, 4 and 7 were recorded at each SU using a Polaris Navigation GPS application version 7.92. This was done because of the tightness of the sites, and that there would not be a great difference between the elevation and GPS coordinates between SU 1 and 4, and SU 4 and 7.

Land use categories

Land use categories were used to test if there is a statistical difference between land use type (LUT) along the riparian zone and grasshopper richness, abundance, composition and the distributional groups using Pairwise Tukey-Post hoc tests along with Primer and Permanova.

Statistical analyses

The response variables were grasshopper species richness and abundance and how they respond to the different LUTs the riparian corridor was tested using Generalized Linear Mixed Models (GLMMs) which were calculated using the *lme4* package in R (2015, The R Foundation for Statistical Computing; Bates 2005). GLMMs were calculated using a Laplace approximation and data fitted to a Poisson distribution (Bolker *et al*. 2009). This was done to illustrate the distribution of grasshopper species richness and abundance within the general study area between the various LUTs. Further, GLMMs (with Poisson distribution and Laplace approximation) were calculated to determine how the overall and CFR endemic grasshopper species richness and abundance where influenced by the different land use types (LUTs), vegetation cover, average vegetation height of the various vegetation growth forms as fixed variables and elevation and day as the random effect. The CFR endemic grasshopper species richness and abundance, however had LUT, vegetation height, vegetation cover, bare ground cover, rockiness, dead litter cover, and presence/absence of the vegetation growth form types as fixed effects and elevation and day as a random effect. Pairwise Tukey post-hoc tests were performed on all significant discrete factors using the *multcomp* package in R (Hothorn *et al*. 2008) including on LUTs and to determine if LUTs have a significant impact on the various distributional groups.

Species assemblage similarities and how it is affected by the fixed factors was calculated using permutational multivariate analysis of variance (PERMANOVA) in Primer 6 version 6.1.13 and Permanova+ version 1.0.3 (Primer-E 2009). F and p values were calculated using 9999 permutations (Anderson 2006). For these analyses, the data were square-root transformed to reduce the weight of common species, and analyses were performed using Bray-Curtis similarity measures (Anderson 2001) PERMANOVAs were constructed for all grasshopper species and CFR endemics, South African endemics (only endemic to South Africa) and into African widespread species (present everywhere in Africa, usually generalist species) in response to the various LUTs and vegetation categories. Species accumulation curves were also constructed along with their relevant Chao2 (±SD) and Jacknife2 values to indicate sampling effort and if it is sufficient.

Results

Grasshopper species richness and abundance

A total of 25 species (1363 individuals) belonging to 11 subfamilies and 4 families were sampled across the entire study area (Appendix D). Ten species were sampled along the natural riparian area, 15 along the agriculture area, 18 along the cleared area, seven along the invaded area, and nine along the urban riparian area (Appendix D). To summarize the highest grasshopper species was sampled in the cleared area.

Significant differences in species richness among the different environmental fixed factors were found for vegetation cover, average vegetation height and different land use types (LUTs) (Table 3.1). Only these three fixed factors had a significant influence on grasshopper species richness.

The different LUTs had a significant influence on grasshopper species richness (Table 3.1). There was a significant difference in grasshopper richness between the cleared and invaded riparian zones as well as between the cleared and the urban riparian zones (Figure 3.5).

A total of 87 grasshoppers were sampled along the natural riparian area, 290 in the agricultural area, 414 in the cleared area, 122 in the invaded area and 450 grasshoppers along the urban riparian area, their means with their standard errors are indicated in the figure below (Appendix D). In short, the highest grasshopper abundance was recorded in the urban riparian area.

There was a significant difference between grasshopper abundance and the different LUTs ($\chi^2 = 629.05$; $p<0.001$), indicating that LUTs had a significant effect on grasshopper abundnace. Overall general grasshopper abundance was significantly influenced by distance from the river's edge, vegetation cover, bare ground and by the different LUTs (Table 3.1).

Overall grasshopper abundance was significantly different between the cleared and agricultural riparian zones (Figure 3.6).

Table 3.1Generalized Linear Mixed Model analyses to determine if the environmental variables had a significant influence on overall general grasshopper species richness and abundance. LUTs = land use types.

Environmental variables	Overall grashopper richness	Overall grasshopper abundance
Distance	6.94	18.09 *
Vegetation cover	4.09 *	5.18 *
Average height of vegetation	0.03	0.39
LUTs	12.33 *	11.82 *
Rock cover	1.56	2.19
Bare ground cover	2.41	6.45 *
Dead biomass cover		1.48

Values represent Chi-squared values for differences in the observed and expected results. *($p<0.05$)

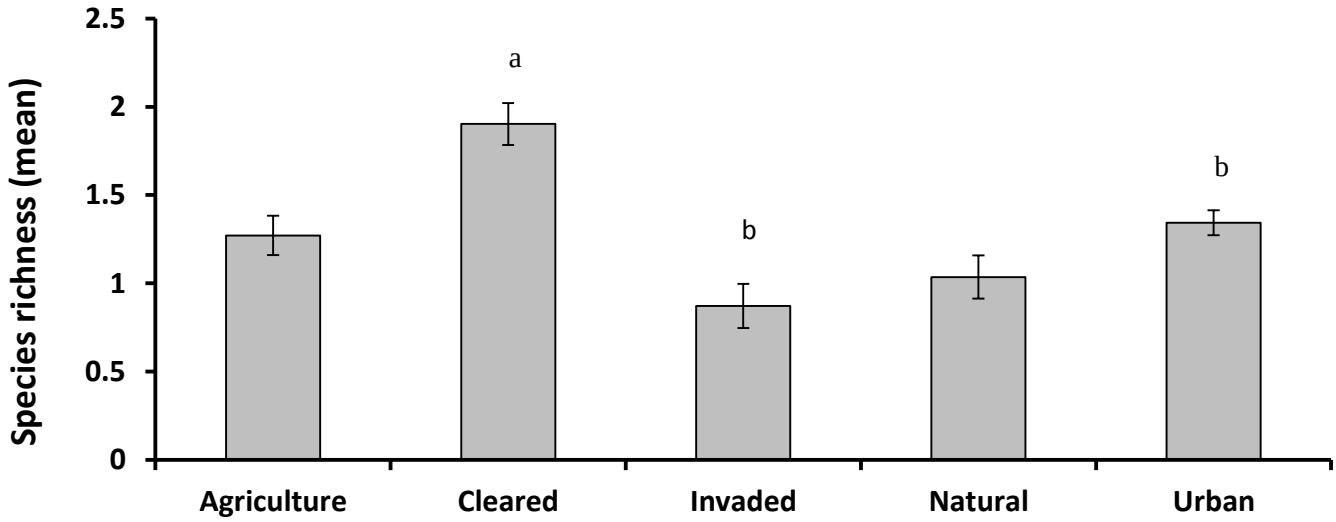

Figure 3.5. Pairwise Tukey post-hoc test on overall species richness across the different land use types, letters represent a significant difference (Mean ±1SE).

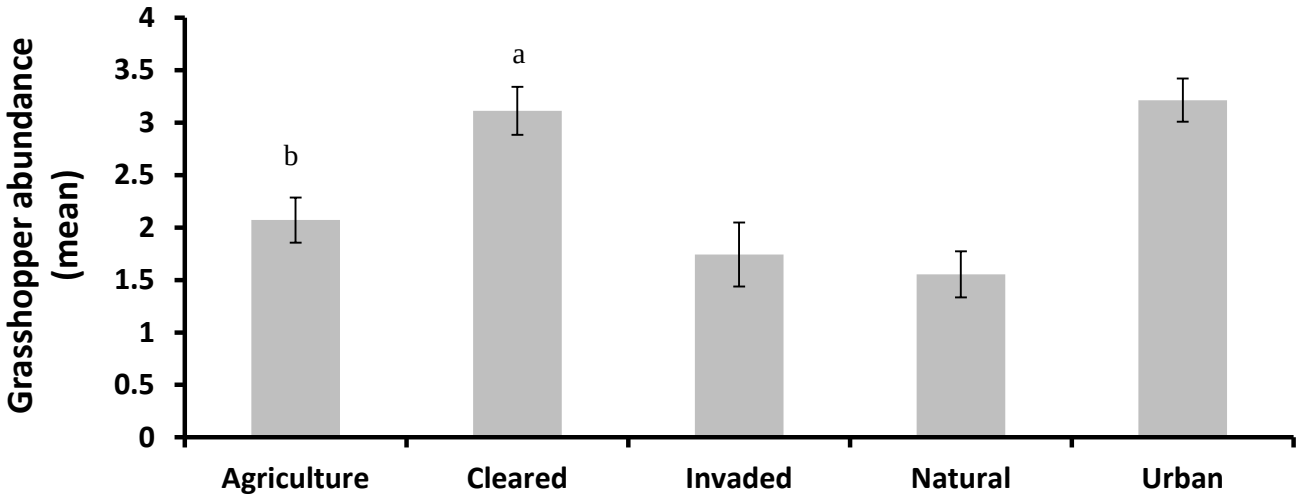

Figure 3.6. Pairwise Tukey post-hoc test on overall mean grasshopper abundance, letters represent significant difference (Mean ±1 SE).

Cape Floristic Region endemic species richness and abundance

Of the 25 species that were sampled only eight were CFR endemic species, four are in the Acrididae and four are in the Lentulidae (Appendix D). CFR endemic species richness and abundance were both significantly influenced by the different land uses, having no species present in either the urban or

invaded areas (Figure 3.7 and 3.8). There was a significant difference in CFR endemic grasshopper abundance between the cleared and agricultural riparian areas (Figure 3.8). CFR endemic species richness was significantly influenced by the presence/absence of shrubs and the presence/absence of grass (Table 3.2). CFR endemic richness was highest in the presence of shrubs and grasses (Appendix B.4). CFR endemic abundance was significantly influenced by the presence/absence of trees, shrubs, herbaceous plants, restios, grass and reed presence/absence (Table 3.2). In the presence of trees, CFR endemic abundance was very low, whereas CFR endemics had high abundance in the presence of shrubs, restios, reeds, grass and herbaceous plants (Appendix B.5).

Table 3.2. Generalized Linear Mixed Model analyses on Cape Floristic Region endemic species richness and abundance in the entire study area to determine if the environmental variables have a significant influence on their richness and abundance

Environmental variables	Endemic species richness	Endemic species abundance
Distance	6.50	9.89
Vegetation cover	0.53	0.16
Average height of vegetation	0.55	1.19
LUT	28.80*	31.75*
Rock cover	0.46	0.17
Bare ground cover	0.45	0.07
Dead biomass cover	0.22	0.03

Values represent Chi-squared values representing differences in the observed and expected results.
*($p<0.05$)

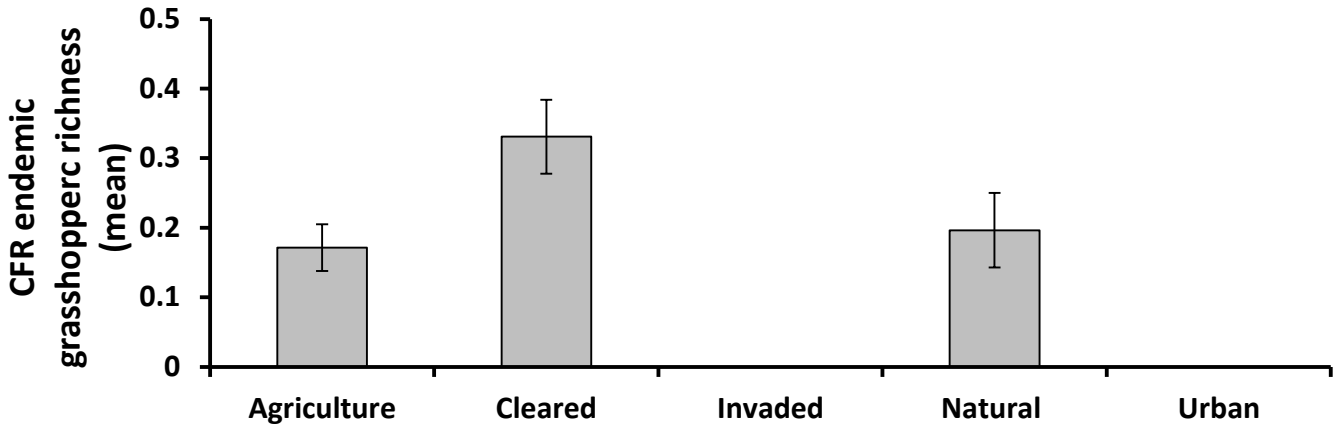

Figure 3.7. Pairwise Tukey post-hoc test on Cape Floristic Region endemic species richness across the different land uses (Mean ±SE).

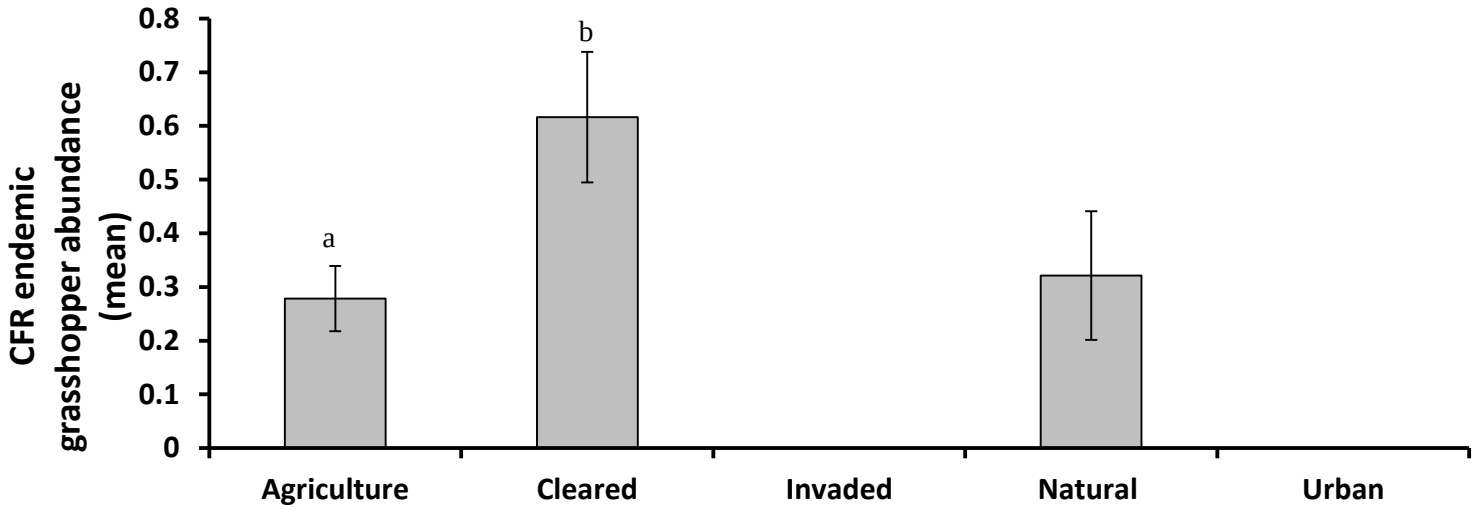

Figure 3.8. Pairwise Tukey post-hoc test on Cape Floristic Region endemic species abundance across the different land uses (Mean ±SE).

South African endemic and African widespread grasshopper species

A total of 566 South African endemic individuals from five subfamilies of the Acrididae and 658 widespread individuals from three subfamilies of the Acrididae were sampled (Appendix D). The most abundant species in the study area were the African widespread species, while the least abundant were the CFR endemic species (Appendix D).

There was a significant difference between South African endemic grasshopper richness and abundance and the following LUTs: the cleared and agricultural riparian area, the natural riparian and agricultural

riparian area, invaded and cleared riparian area, urban and cleared riparian area, natural and invaded riparian area amd lastly between the urban and natural riparian area (Figure 3.9 and 3.10).

There was a significant difference between the African widespread grasshopper richness the natural, agricultural, cleared and urban riparian areas (Figure 3.11). There was also a significant difference between African widespread abundance among the natural, agricultural and urban riparian areas as wellas between the urban and cleared riparian areas (Figure 3.12).

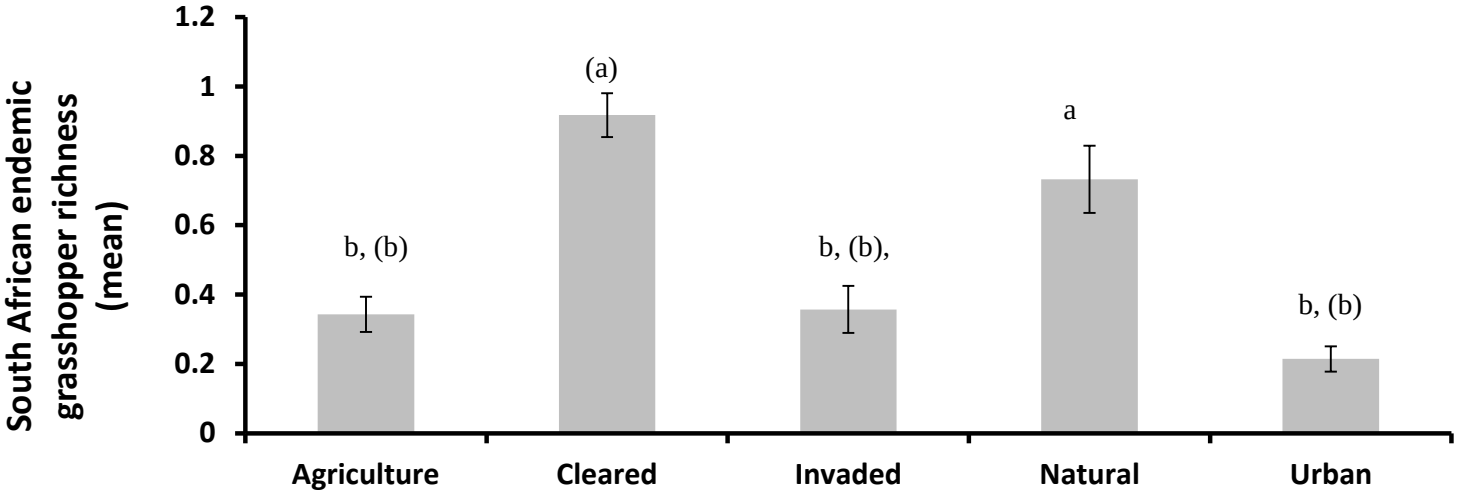

Figure 3.9. Pairwise Tukey post-hoc test on the mean South African endemic grasshopper richness, letters represent significant differences (Mean ± 1SE).

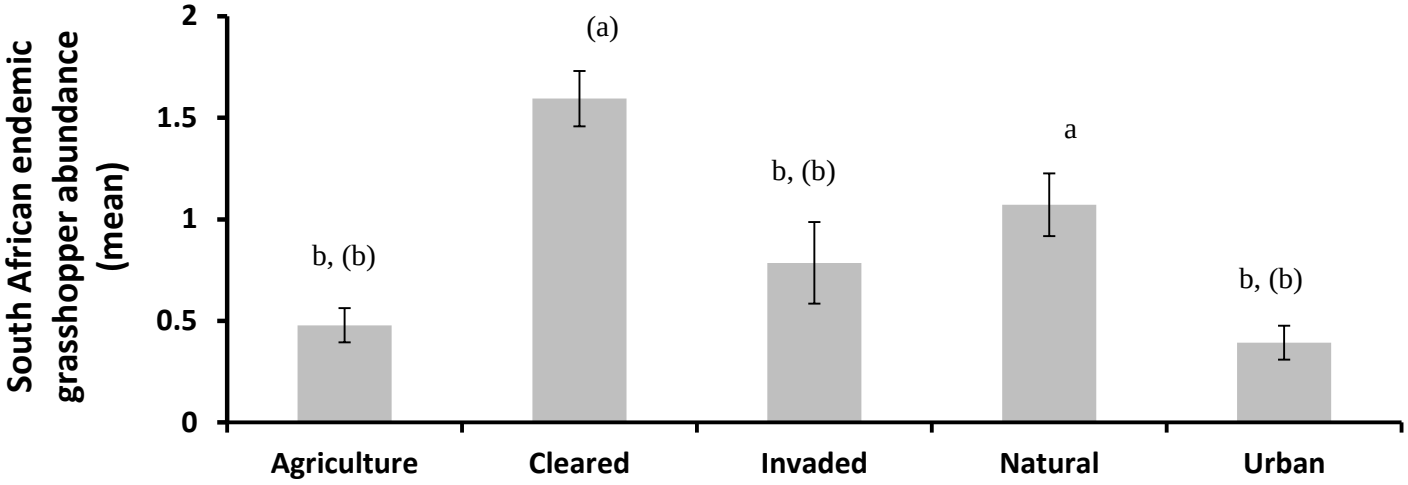

Figure 3.10. Pairwise Tukey post-hoc test on the mean South African endemic grasshopper abundance, letters represent significant differences (Mean ± 1SE).

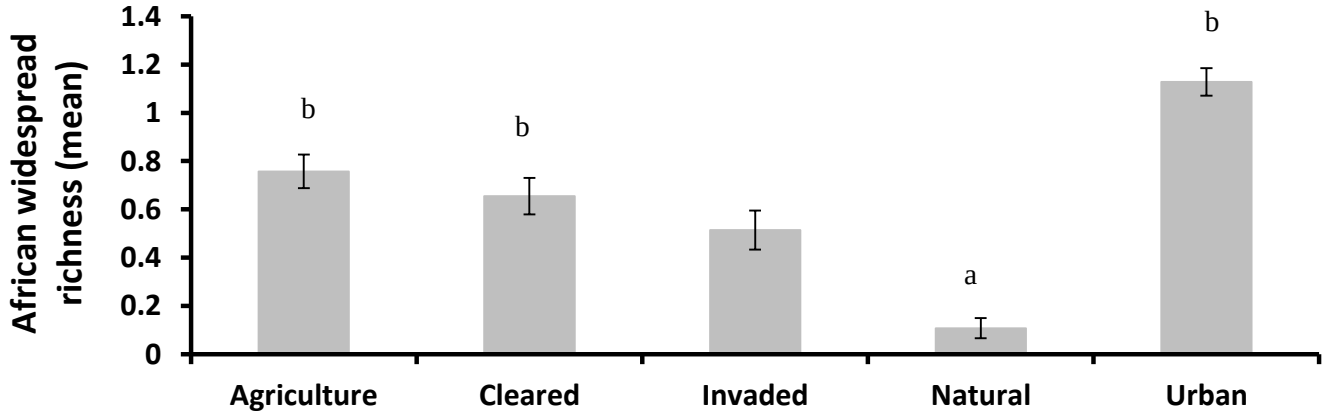

Figure 3.11. Pairwise Tukey post-hoc test on the mean African widespread grasshopper richness, letters represent significant differences (Mean ± 1SE).

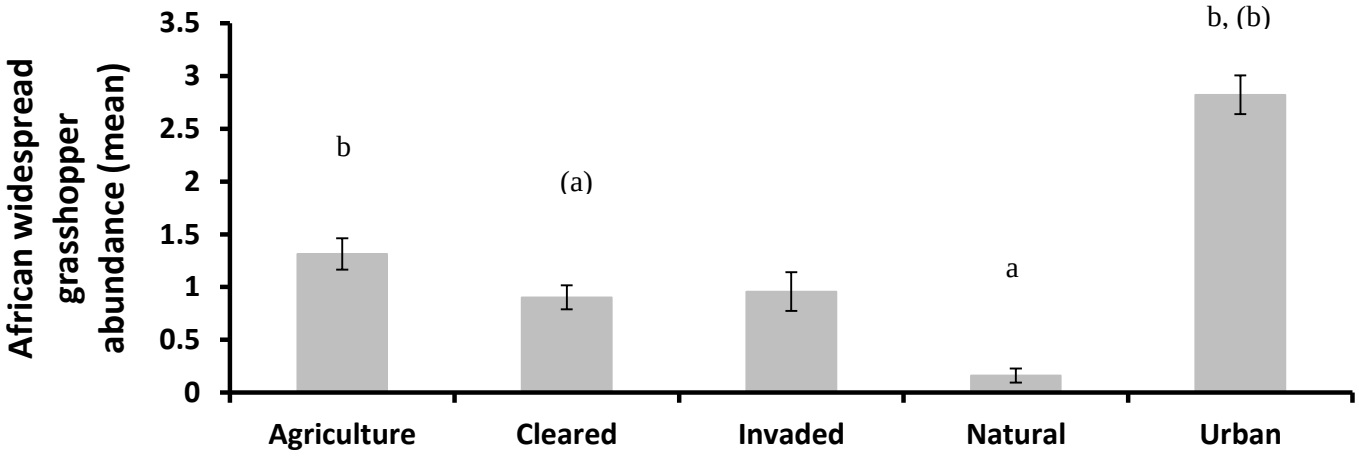

Figure 3.12. Pairwise Tukey post-hoc test on the mean African widespread grasshopper abundance, letters represent significant differences (Mean ± 1SE). *Assemblage composition*

Overall assemblage composition

There was a significant difference in assemblage composition and the various LUTs in general (Table 3.3). There is a significant difference between species composition of the agricultural riparian and cleared riparian, agriculture riparian and urban riparian, agriculture and invaded riparian, cleared and urban riparian cleared and invaded riparian and between urban and invaded riparian areas (Table 3.3).

Table 3.3. Permutational multivariate analyses of variance (PERMANOVA) and associated pairwise tests between grasshopper assemblage composition and the different land use types.

	Pseudo-F	t-value	df	p-value
Land use types	26.68		4	0.001*
Agriculture- Cleared		4.98		0.001*
Agriculture – Urban		6.50		0.001*
Agriculture - Invaded		2.49		0.001*

Cleared – Urban	7.90	0.001*
Cleared – Invaded	4.90	0.001*
Urban - Invaded	7.67	0.001*

Values represent t-values by pair wise comparison. Number of permutations 9999.

Endemic versus widespread species

The CFR endemic species composition was highly influenced by the different land use types (Table 3.4)There was a significant difference between the CFR endemic species along the natural riparian area and cleared area, agriculture and cleared area, agriculture and urban area, agriculture and invaded area, cleared and urban area and lastly between the cleared and invaded area (Table 3.4).

Table 3.4. Permutational multivariate analyses of variance (PERMANOVA) and associated pairwise tests of Cape Floristic Region endemic grasshopper species composition and the different land use types.

	Pseudo-F	t-value	df	p-value
Land use types	19.17		4	0.001*
Natural riparian - cleared		1.74		0.05*
Agriculture- Cleared		3.46		0.001*
Agriculture – Urban		4.74		0.001*
Agriculture - Invaded		3.28		0.001*
Cleared – Urban		8.96		0.001*

Cleared – Invaded	5.31	0.001*

Values represent t-values by pair wise comparison. Number of permutations 9999.

Relative abundance

In general, the most abundant grasshopper species were *E. calceata, A. thalassinus* (Acrididae) and *Conocephalus maculatas* (Tettigoniidae), the only katydid which could be analyzed in this study since it is diurnal and therefore adequately sampled alongside grasshoppers, using the same methodology (Appendix C). The most abundant CFR endemic species was *E. umoja*, which was most abundant in both the agricultural and cleared riparian areas, while *K. capicola* was most abundant in the cleared riparian area (Appendix C). *F. laevata* (1 individual), *Betiscoides* sp. (13 individuals) and *G. cuneatum* (3 individuals) were the only three CFR endemic species that were sampled in the natural riparian area but nowhere among the transformed LUTs. Interestingly the only CFR endemic grasshopper that was sampled in the natural riparian area and also among the transformed LUTs was *K. capicola. S. saucia, D. capensis* and *D. coryphistoides* were among those CFR endemic grasshoppers species that were sampled within the cleared and riparian area and not within the natural riparian area, howevere their number of individuals sampled were very low.

Sampling effort

Throughout this study sampling effort was mostly sufficient enough according to the species accumulation curve (Table 3.5).

Table 3.3. Species richness estimators for the individual land use types (riparian zones) as well as a combination of all the land use types.

Species richness estimators			
	Sobs	Chao2 (±SD)	Jacknife2
Combined land use types	25	31.25 (7.55)	32.98
Natural riparian zone	10	12.25 (3.40)	13.95

Agricultural riparian zone	15	16.5 (2.30)	18
Cleared riparian zone	18	30.5 (17.14)	26.91
Invaded riparian zone	7	7 (1.05)	8.96
Urban riparian zone	9	11 (3.74)	11.98

Discussion

Riparian corridors in Mediterranean type ecosystems such as the CFR occupy small areas of the region therefore being more vulnerable to the impacts of anthropogenic activities (Stella *et al.* 2013). The riparian vegetation of mediterranean regions differs to that of their mesic temperate and tropical counterpart regions in that they host high local plant diversity and a greater proportion of the biome's tree species (Stella *et al.* 2013). Different land uses along river systems impact and alter the riparian vegetation composition and structure. Therefore, the natural riparian vegetation architecture is completely different to the architecture of riparian vegetation that has been impacted or affected through human-induced activities. During my studies there was a visual difference and clear alteration in vegetation architecture along the river and in the separate land uses, with no one LUT 100% resembling one another. This is owing to anthropogenic activities such as agriculture, urbanization and land clearing which all enhances the proliferation and establishment of invasive alien plants, especially invasive alien trees along the river. It is also clear from my results that vegetation architecture (cover, Table 3.1) along the Lourens River has a significant influence on overall grasshopper species and abundance which may be as a result of the alteration in vegetation architecture and the presence of invasive alien-trees.

In this study area the most dominant invasive alien trees includes the following: *Eucalyptus*, *Acacia longifolia*, *A. mearnsii*, *Hakea* sp., *A. cyclops* and *A. saligna*. These invasive alien tree species are the most dominant and general species that are found in the CFR and along the Lourens River in Somerset West. The establishment of invasive alien trees is therefore most concentrated along riparian zones degrading the natural riparian vegetation and displacing native fauna. This disturbance has led to the decrease and loss of riparian habitats and species whilst also decreasing the connectivity between riparian zones (Naiman *et al.* 2005). Hereby decreasing the naturalness of the riparian zones and adding to the loss of riparian and terrestrial species that is adapted to the dynamic nature of natural river systems. These natural river systems where anthropogenic modifications of the natural environments are encountered may become threatened and as a sreuslt threaten their survival (Smith *et al.* 2009). Therefore, invasive alien vegetation in general has a significant negative influence on many ecological variables, such as ecosystem functioning and on invertebrate species.

Strongly dominating alien plant species such as the species mentioned above, are prone to cause changes in species, communities and/or ecosystems (Vila *et al.* 2010). Invasive species can threaten biodiversity

and among other things reduce genetic variation and erode gene pools via the extinction of endemic species (Hulme 2007). In my findings there were no CFR endemic grasshopper species in both the invaded and urbanized riparian zones. This may be as a result of invasive alien vegetation being capable of replacing indigenous plant species, such as fynbos, especially along waterways. This again changes the vegetation architecture and it could be speculated from my findings that most CFR endemic grasshoppers that are completely reliant on fynbos plants will not be capable of surviving in these new and altered habitat types. This is supported in my findings that CFR endemic grasshoppers are completely absent from invaded and urbanized riparian areas (Figure 3.8 and 3.9).

The invaded riparian zone has the least overall grasshopper richness which was significanltly different to the cleared area but not to the natural riparian area (Figure 3.5). It can be therefore speculated that the cleared riparian area may be more speciose than the natural riparian area. It is unsure what may be causing this richness whether it may be vegetation architecture and composition or the level of disturbance. This invasion process most probably will cause long-term changes to the natural vegetation composition and associated alterations to the habitat structure (Yoshioka *et al* 2010). This can result in native species being lost from these areas. It is also well documented that terrestrial phytophagous insects are significantly impacted by plant invasion and some species may increase or decrease in abundance as a result of invasion (Yoshioka *et al.* 2010). This substantiates my findings that the invaded riparian area may be less speciose when compared to the other LUTs. The natural riparian area had the least abundance of grasshoppers, but there was only a significant difference between the cleared and agricultural riparian areas (Figure 3.6). My findings show that mean grasshopper abundance is highest in the urbanized riparian zones compared to the rest of the LUTs but there was no significant difference between the urbanized and the rest of the LUT riparian areas.

It is also noted that the African widespread species richness and abundance are most abundant within the urban riparian areas where it is significantly different to the natural and cleared riparian areas, whereas CFR endemic grasshoppers and South African endemic grasshoppers were present at low abundance or not present at all. Even though urbanization and invasion by alien plants species are known to reduce the biodiversity and/or abundance of invertebrates, specifically insects (Samways and Moore 1991; Yoshioka *et al*. 2010), which are essential components in terrestrial ecosystem food webs (Tallamy 2004). My findings contradict the fact that there will be a decrease in invertebrate abundance in urbanized riparian zones. It can be suggested that the high abundance of wide spread African grasshopper species in these two zones are attributed to them being generally generalist species and are readily capable of adapting to a mixture of plant species invasive and exotic. However, they may not be as adapted and capable of surviving in the natural fynbos vegetation as they are extremely less abundant in the natural riparian zone. However they are present within the cleared riparian areas, which may suggest that within some areas of the cleared riparian areas there may still be an intermixture of fynbos, exotic and invasive alien vegetation.

Urbanization is consequently associated with habitat loss as it involves the breaking apart of a once continuous natural habitat into smaller fragmented patches via the intrusion of housing developments, industrial parks and transportation infrastructure (Lindenmayer and Fischer 2006). This leads to the extirpation of native species from ecosystems, such as riparian zones. This is in accordance with my findings that CFR endemic grasshoppers are primarily absent from these areas of invasion and disturbance (urban riparian vegetation and invaded riparian vegetation).Thus emphasizing how negatively

CFR endemic grasshoppers are affected by disturbance and invasion and that they do become extirpated within these riparian zones. Because they are so negatively affected they could be viable bioindicators, especially *Betiscoides* sp. as it was the most abundant CFR endemic grasshopper sampled in the CFR along riparian vegetation zones, as most endemic invertebrates make for good bioindicators (Samways *et al.* 2010).

The cleared riparian zone, interestingly enough had the most overall grasshopper richness and abundance. I also found a more striking result in my study which is that CFR endemic grasshoppers have the highest species richness and abundance within the cleared riparian zone and the second most in the agricultural riparian zone whereas the lowest species richness and abundance was found within the natural riparian zone, but technically the urban and invaded areas had the lowest amount of CFR endemic grasshoppers as these two riparian areas were barren of them. The agricultural riparian zone has a semi-natural vegetation composition and is separated from the farming practices by a gravel road. The cleared riparian zone was relatively open also with a semi-natural vegetation composition. Therefore these riparian zones undergo intermediate disturbance, unlike the urbanized and invaded riparian zones that experience high levels of disturbance. The high diversity and abundance of grasshoppers in the cleared and agricultural riparian zones can be explained by the Intermediate Disturbance Hypothesis (IDH). According to the IDH, in situations that experience an intermediate disturbance there will be highest species diversity, as it constrains competitive exclusion, in so doing it allows the coexistence of taxa with divergent species traits and adaptive strategies (Ward *et al.* 2002). Therefore, explaining the co-occurrence of CFR endemic, South African endemic and African widespread grasshopper species within these riparian zones. This is however a speculation on studies that have been done in river dynamics which have found highest species diversity in situations that have intermediate disturbances as there has only been limited attempts to test the IDH in complex riverine systems such as riparian zones (Salo *et al.* 1986; Ward *et al*. 2002).

This could also be indicative of the importance on clearing land from invasive alien plants, as restoration/rehabilitation of these areas are critically important for CFR endemic grasshoppers. This also suggests that these areas, especially along the Lourens River, have little impact on the riparian vegetation of these two zones, the cleared and agricultural zones, implying that conditions within these areas and thus management (as both of these zones are situated on mostly Vergelegen wine estate and Lourensford wine estate) are of good quality. However, it should be taken into account that the grasshoppers are mainly indicative of the riparian vegetation and not water quality as they are terrestrial invertebrates. Therefore, in order to determine water quality they could be used in conjunction with the Dragonfly Biodiversity Index (DBI) as riparian vegetation generally aids and affects the quality of the water.

In light of the different disturbance scales along the riparian zones in each land use, it can be predicted that high disturbances (invasion and urbanization), intermediate disturbances (cleared and agriculture) and low/no disturbances (natural) may influence grasshopper diversity and abundance along riparian zones in the CFR. The natural riparian zone, representing the low/no disturbance has the lowest overall grasshopper species abundance. This suggests that the level of disturbance may have an impact on grasshopper richness and abundance in the CFR. However, it can also suggest that natural disturbances in the fynbos, especially in the natural riparian zone do not promote grasshopper diversity and abundance in the CFR. Whereas it is known that natural disturbances in the CFR, i.e. fire, generally stimulate floral diversity and speciation (Cowling *et al.* 2004), one would expect the same to be true for the faunal aspect.

In terms of vegetation composition, shrub, restio, herb and grass cover had a significant influence on grasshopper species richness, whereas shrub, restio, herb, grass and reed cover significantly influenced grasshopper abundance. These are all important factors influencing grasshopper richness and abundance, and can be important factors shaping grasshopper habitat, providing shelter, oviposition sites and feeding resources for the various grasshopper species (Guido and Gianelle 2001; Kati *et al*. 2004; Zografou *et al*. 2009).

Of the CFR endemic grasshoppers *E. umoja* is the most abundant species in both the cleared and agricultural riparian zone. This species is only known from Somerset West (Spearman 2013), making it vulnerable to changes occurring in this area. This suggests that it may have value as a bioindicator for environmental change and disturbance. This species may be found in more open habitats and explains its high abundance within these two riparian zones, indicating as well that the natural riparian vegetation may be too dense for this fynbos endemic grasshopper. Another CFR endemic grasshopper, *K. capicola*, is also the only species present within the cleared riparian zone and in the natural riparian zone. Because of this, this species may also have value for being a bioindicator as it is present in the natural riparian vegetation and hence persists under 'natural' conditions. This may suggest that the cleared riparian zones are operating under semi-natural conditions, emphasizing the importance of clearing invasive alien trees and keeping the vegetation sparse and relatively low, as it may more closely relate to the natural fynbos terrain. Of the CFR endemic grasshoppers, only *Betiscoides* sp., *G. cuneatum* and *F. laevata* were restricted in the natural riparian zone. This suggests that they may be fynbos plant specialist, as it is already known about *Betiscoides* sp (Matenaar *et al* 2014).

The presence and absence of shrubs, trees, herbs, restio, grass and reeds significantly influences CFR endemic grasshopper abundance, whereas only shrubs and grass influence CFR on endemic grasshopper species richness. This may link to what was previously mentioned that these may be important factors These are all important factors influencing CFR endemic grasshopper richness and abundance, and can be ainfluencing and shaping the natural grasshopper habitat (Guido and Gianelle 2001; Kati *et al*. 2004; Zografou *et al*. 2009).

The South African endemic grasshoppers are also highly abundant and species rich within the cleared riparian zone and then in the agricultural riparian zone there is however a significant difference between the cleared and the invaded, urban and agricultural riparian areas, which may be suggestive of the vegetation architecture or the abundance of bare ground within the cleared riparian areas. This further emphasizes the negative effect that these land uses have on endemic grasshopper species and abundance.

African widespread species are less influenced by urbanization as a land use type along the riparian vegetation and seem to flourish in the urban riparian areas, and from my findings there is a significant difference in both their richness and abundance between the LUTs. Their species richness is significantly different between the urban and natural riparian area, whereas there is a significant difference in their abundance between the urban and both the natural and cleared riparian areas. Thus it could be speculated that the natural and cleared riparian areas are not favourable for the African widespread species which may be as a result of the vegetation architecture or the availability of perch sites and food sources. Their abundance and richness in the urbanized riparian areas could be related to the increasing heterogeneity of the vegetation composition by various plant species, invasive and aesthetic (Pearson 2009). The effect alien plants may have on a species is mainly dependent on the degree of their dependency on alien plants

as food sources (de Groot *et al*. 2007; Gerber *et al.* 2008). The African widespread species, as a result of them being mostly generalist species are therefore more likely to be found in the urban riparian area, due to its mosaic of food sources and habitats. The African widespread species are also however, very low in abundance and species in the invaded riparian zone where it has a negative effect on these species as well.

In numerous occasions there was a significant difference between overall assemblage composition and certain LUTs along the riparian areas of the LUTs. However, there was no significant difference of any of the LUTs with the natural riparian area within the overall general assemblage composition. This could be indicative that many South African endemic and African widespread species may be less occurent within the natural riparian area and that these species differ in their composition between the different LUTs. It can thereby be speculated that some LUTs favour certain assemblages more than others.

On the other hand there was a significant difference in the CFR endemic grasshopper assemblages across all LUTs including the natural riparian area, which was significantly different to the cleared riparian area. This could be as a result of the cleared riparian areas being more open with less shade and less dense whereas the natural riparian area is relatively densely vegetated. It can also be speculated that the cleared riparian area may have a greater mixture of fynbos plant species such as restios, eventhough restio stands do occur within the natural riparian area but may be to a lesser extent than in the cleared riparian area. Another speculation could be due to the cleared riparian area undergoing rehabilitation and may resemble the natural terrestrial fynbos environment.

In conclusion, it can be speculated that CFR endemic grasshoppers may have bioindication value in the CFR in the riparian zones, as they are present in both the cleared riparian and natural riparian zones, especially *K. capicola* and *E. umoja*. However, this theory has to be tested along other riparian zones in the CFR, as this is only true for the Lourens River in Somerset West. The conservation of riparian zones in the CFR is of high conservation importance as it provides a habitat for many CFR endemic grasshoppers. This indicates that there may be a mosaic of fynbos plants intermixed with agricultural practices and furthermore that this zone, especially on Vergelegen and Lourensford may also be well managed and have little impact on the riparian vegetation.

The absence of CFR endemic grasshoppers in the urban and invaded riparian zones further indicates their value of being a bioindicators for riparian vegetation quality and health. As expected invasive alien trees in general have a negative impact on biodiversity and especially along riparian zones where they have a negative impact on all grasshopper species, both endemics and widespread grasshopper species according to my findings. This emphasizes the importance of managing and controlling invasive alien trees and eradicating them from riparian zones, especially in the CFR and along the Lourens River. With the clearing and eradication of invasive plants, natural grasshopper species may return to these riparian zones, increasing the biodiversity along riparian zones. This is supported by the finding in my study that cleared riparian zones have the highest grasshopper abundance and are the most grasshopper speciose.

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Chapter 4: Discussion and conclusion

The vegetation architecture in the natural riparian terrestrial zone in the Cape Floristic Region (CFR) may have had an influence on the dispersion of grasshopper species, especially CFR endemic, South African endemic and African widespread grasshoppers. It is not unusual that grasshoppers are influenced by the architecture of the vegetation, as this has been well documented (see Gebeyehu and Samways 2002; Bazelet and Samways 2012; Crous *et al.* 2014). In both chapters, the grasshopper species were categorized into their distributional categories i.e. CFR endemic, South African endemic and African widespread grasshoppers.

I found that in the natural riparian and terrestrial zones, there was the same number of CFR endemic and South African endemic grasshopper species richness, whereas the African widespread grasshopper species were relatively poorly represented and were relatively low in these two natural zones (Chapter 2). However, South African endemic grasshopper species were most abundant in the natural areas with the CFR endemic grasshoppers having almost the same abundance whereas the African widespread grasshopper species had low abundancies in these two natural zones. In my study I found that the CFR endemic grasshoppers in the natural areas were not affected by vegetation cover or height (Chapter 2). This can be expected as they are adapted to the architecture of the fynbos vegetation. However, they are significantly influenced by the presence of ferns, shrubs and herbaceous plants. It was found that they are absent in the presence of fern plants, and it can be speculated that this could be as a result of it being a pioneer plant and their unpalatability or uniformness. Pioneer plants are usually plants that occur after a disturbance and are the first plants to vegetate the area after having been recently disturbed. It can be concluded that the absence of CFR endemic grasshoppers in the presence of fern plants is because of a recent disturbance in the environment. On the other hand they are present in the presence of both shrubby and herbaceous plants, which may be an important factor shaping CFR endemic grasshopper habitat, providing shelter and feeding resources (Guido and Gianelle 2001; Kati *et al*. 2004; Zografou *et al*. 2009).

In general the CFR endemic grasshoppers are associated with the terrestrial zone. However some species are dispersed across both these zones, especially in the case of *Betiscoides* sp. and *Gymniduim cuneatum.* There is a general tendency in the natural riparian and terrestrial zones that grasshopper species richness and abundance decreases from the riparian zone into the terrestrial zone, with the lowest abundance of grasshoppers in the furthest terrestrial site i.e. terrestrial site three. This could be indicative that certain grasshopper species that are not adapted to the fynbos vegetation will more likely be present within the riparian zone due to the intermixture of vegetation. Species composition is also different between these two zones. According to my findings there exists a riparian grasshopper fauna in the CFR. There is also a significant difference between the CFR endemic grasshopper species composition between these two natural zones. In addition to this finding it can be suggested that CFR endemic grasshoppers do exist in a non-biome specific riparian corridor in the natural environment of the CFR.

In generally there seems to be a visual association, according to my findings, between the South African endemic and African widespread grasshopper species and the riparian zone in the natural environment of the CFR. Whereas most CFR endemic grasshopper species were more visually associated to the natural terrestrial zone due to their affiliation with certain fynbos plant species, hence their predominance in the terrestrial zone.

Natural ecosystems, especially natural riparian corridors have been relatively disturbed and altered through anthropogenic activities (Richardson *et al.* 2007; Stella *et al.* 2013). This has impacted the complexity and biodiversity of natural riparian corridors, leading to the loss of native and endemic species and enhancing the replacement of them by invasive alien and widespread species. This is the result of various land use practices that occur along the riparian corridor, and in my study these included agricultural practices, urbanization, invasion by alien-tree species and a cleared area of invasive alien-tree vegetation (Chapter 3). All the different land uses have varying disturbance levels that exert different impacts on the natural, endemic and native species that occur within riparian corridors.

Orthoptera are very sensitive to environmental change, thereby making them good indicators for environmental and land use change (Samways 1997; Armstrong and van Hensberen 1999), as well as being sensitive to habitat deterioration and human-induced landscape changes (Steck 2007). It is clear from my findings that land uses along the riparian zone significantly influence grasshopper species richness, species composition and abundance.

It can also be speculated that the level of disturbance also has an influence on grasshopper richness and abundance. According to the Intermediate Disturbance Hypothesis (IDH), moderate human-induced disturbances may be more beneficial for biodiversity than no/low and high disturbances in the environment (Kati *et al*. 2012). I found that both the cleared and agricultural riparian areas, areas of intermediate disturbance, had the most grasshopper species richness and abundance, whereas compared to the cleared and agricultural riparian areas the natural riparian area had fewer grasshopper species and abundance. In addition, most CFR endemic grasshoppers were found within both the cleared and agricultural riparian areas, whereas they were absent from the urban and invaded riparian areas, areas of high disturbance, and present in low numbers in the natural riparian area, an area of no/few disturbances. Therefore my findings are in agreement with the IDH, suggesting that grasshopper species flourish in areas with moderately human-induced disturbances such as in the cleared and agricultural riparian areas in the CFR. Also influencing grasshopper species richness and abundance is vegetation cover, the distance from the river's edge and, as mentioned before, the different land use types along the riparian corridor.

The CFR endemic grasshopper species interestingly were most abundant in the cleared and agricultural riparian areas and were least abundant in the natural riparian area. This may suggest that CFR endemic grasshoppers require natural disturbances at an intermediate level to enhance their species richness and abundance within the natural areas of the CFR. This may also infer that natural disturbances such as fire, as the CFR is a fire driven ecosystem, may be altered or absent in the riparian corridor (Bond *et al.* 2003). However, the low levels of disturbances may be as a result of the riparian corridor being protected from natural disturbances such as fire in the CFR. Riparian vegetation is much less prone to fire disturbances. This is because of the differences in fuel characteristics and the upland vegetation, the surrounding terrestrial fynbos, along with the riparian zone usually being protected from fire by the topography of the landscape (Taylor 1978; van Wilgen *et al.* 1990; Dwire and Kauffman 2003; Arkle and Pilliod 2010). Therefore this could explain the richness and abundance of the CFR endemic grasshopper in the natural riparian zone compared to the cleared and agricultural riparian zones that are both areas of intermediate disturbance.

The South African endemic grasshoppers were dispersed across the different land uses along the riparian corridor. However, they were most abundant in the cleared and agricultural riparian areas compared to the natural riparian area. On the other hand, the African widespread grasshopper species were most abundant in the urbanized riparian area and then in the invaded riparian area, again with least abundance in the natural riparian area. This suggests that the African widespread grasshoppers are not adaptable to the natural fynbos vegetation as they only occur in areas that are depleted of natural fynbos vegetation such as in the urban riparian areas. It can thereby be implied that they are more adaptable to the invaded and urbanized riparian areas because of them being widespread generalist species and that most of the plant species that are found within these two riparian zones do not impact them negatively. It appears that the fynbos vegetation and its associated insect, grasshopper fauna are highly specialized and adapted to one another, thus emphasizing the importance of the conservation of this unique vegetation type.

In conclusion, there is a distinct difference in general species composition between the riparian and terrestrial grasshopper fauna which is also seen in the CFR endemic grasshoppers. This strengthens the motivation to conserve both the natural riparian and terrestrial zones as they are both significantly unique in this biodiversity hotspot. Furthermore, land use change along the riparian corridor of the CFR is having a negative impact on natural endemic and native species, both faunal and floral. This is illustrated by the loss of CFR endemic grasshoppers in the urbanized and invaded riparian zones, which indicates that the endemic and native fynbos vegetation is also being lost and replaced.

Invasion has a significant impact on ecosystems across the globe. However, its impact on biodiversity hotspots may be more severe as the uniqueness of these hotspots are becoming lost, and therefore invasive alien-tree eradication and control is utterly important especially along riparian corridors of the CFR. If this invasion is not controlled there is a great chance that more fynbos endemic species may be lost and even become extinct. Grasshopper fauna are good bioindicators, which is illustrated in my findings and can be suggested that certain CFR endemic grasshopper species may be viable candidates, especially, *F. laevata*, *K. capicola* and *E. umoja.* However, the other CFR endemic grasshoppers may also be viable candidates. This is because *Betiscoides* sp. is present in only the natural zones, and dispersed across both the riparian and terrestrial zone, *F. laevata* is also only found in the natural zone, but is very scarce, emphasizing its sensitivity to environmental changes and alterations in the natural areas of the CFR. *K. capicola* and *E. umoja* are both found within the cleared and agricultural riparian areas, indicating that there may be fynbos vegetation present and that circumstances within these area are influencing them strongly as they are most abundant and speciose within these riparian areas. However, the former is also present in the natural riparian zone. Thereby it can be speculated that if this species is capable of surviving within the agricultural and cleared riparian areas, the conditions may be similar to that of the natural riparian area. According to these findings, it is clear that conservation practices are important within these riparian areas, as they are unique and dynamic ecosystems, and with their deterioration drastic losses or increases may occur, significantly impacting a biodiversity hotspot.

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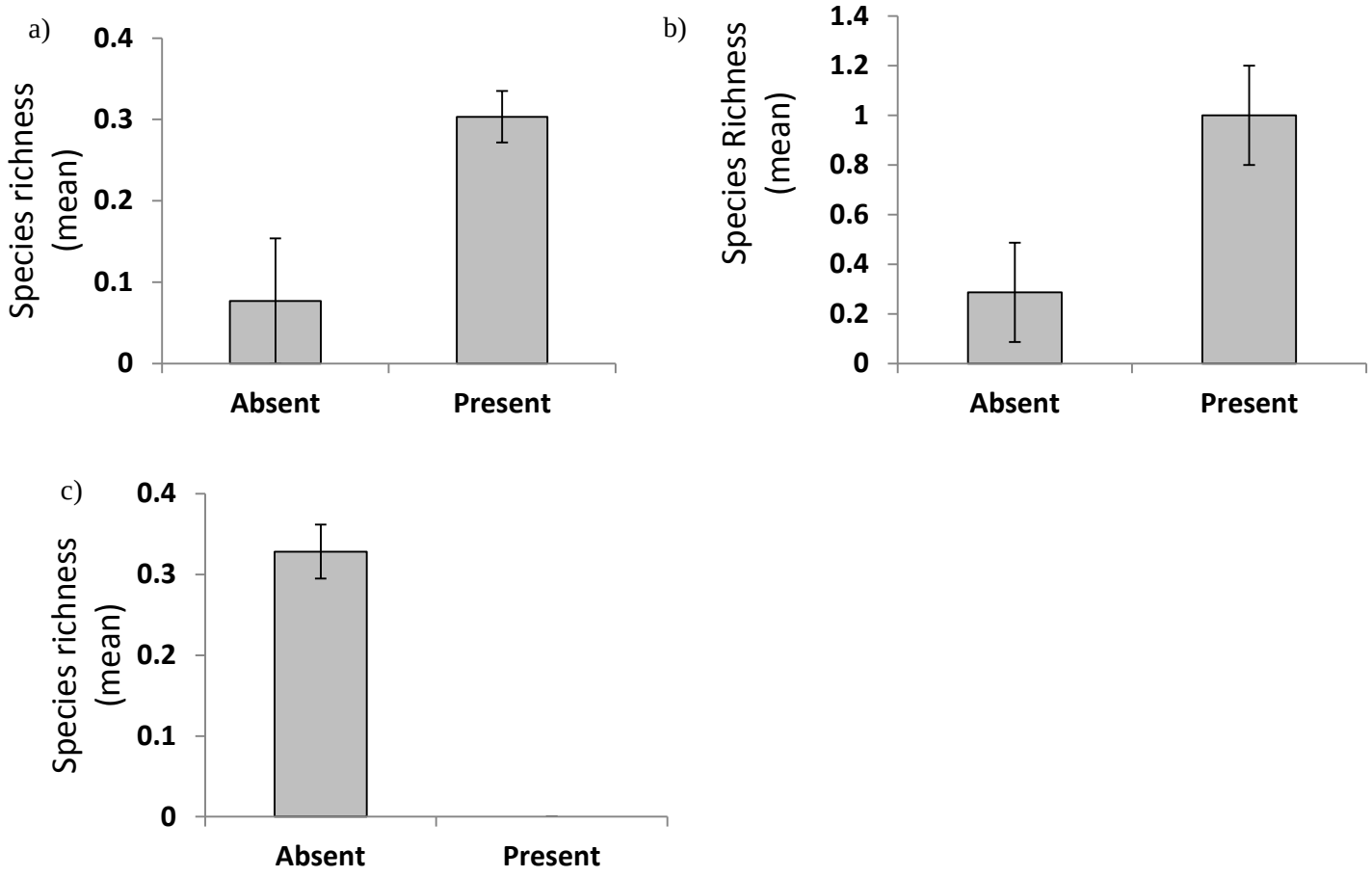
Appendix A. Species and number of individuals sampled in the natural riparian and terrestrial zones.

Family	Subfamily	Species	No. of individuals sampled	Distribution
Acrididae	Acridinae	*Keya capicola* Uvarov, 1941 *	1	CFR
	Catantopinae	*Frontifissia laevata* Dirsh, 1956 *	3	CFR
		Vitticatantops humeralis (Thunberg, 1815) **	49	Western, Eastern and Northern Cape
	Cyrtacanthacridinae	*Acanthacris ruficornis ruficornis* (Fabricius, 1787) ***	19	Africa
	Eyprepocnemidinae	*Eyprepocnemis calceata* (Serville, 1838) **	65	Southern Africa
	Oedipodinae	*Acrotylus patruelis* (Herrich-Schäffer, 1838) ***	1	Africa
		Heteropternis pudica (Serville, 1838) **	2	Southern Africa
		Sphingonotus nigripennis (Serville, 1838) **	1	Southern Africa
Lentulidae	Lentulinae	*Betiscoides* sp.*	82	Restio stands in the CFR
		Gymnidium cuneatum (Rehn, 1944) *	7	CFR

(*) CFR endemic species, (**) South African endemic species, (***) African widespread generalist species

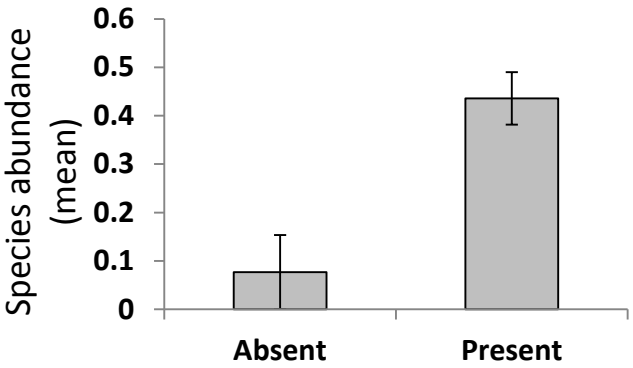
Appendix B. Shows species richness and abundance responses to various variables

Appendix B.1. CFR endemic species richness and the presence/absence of vegetation growth forms, a) Shrub, b) Herbs and c) Ferns (Mean ±1SE).

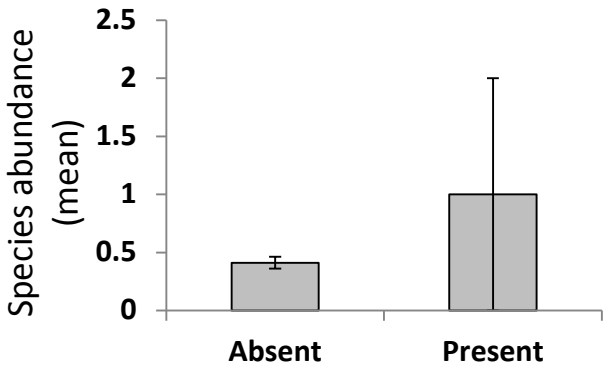


Appendix B.2. CFR endemic species abundance and the presence/absence of vegetation growth forms, a) Shrub, b) Herbs and c) Ferns (Mean ±1SE).

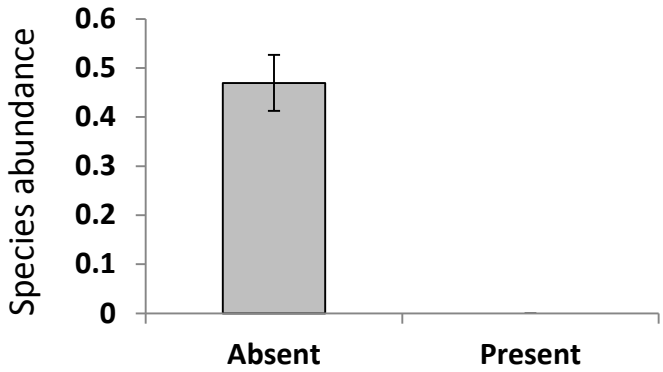
a)



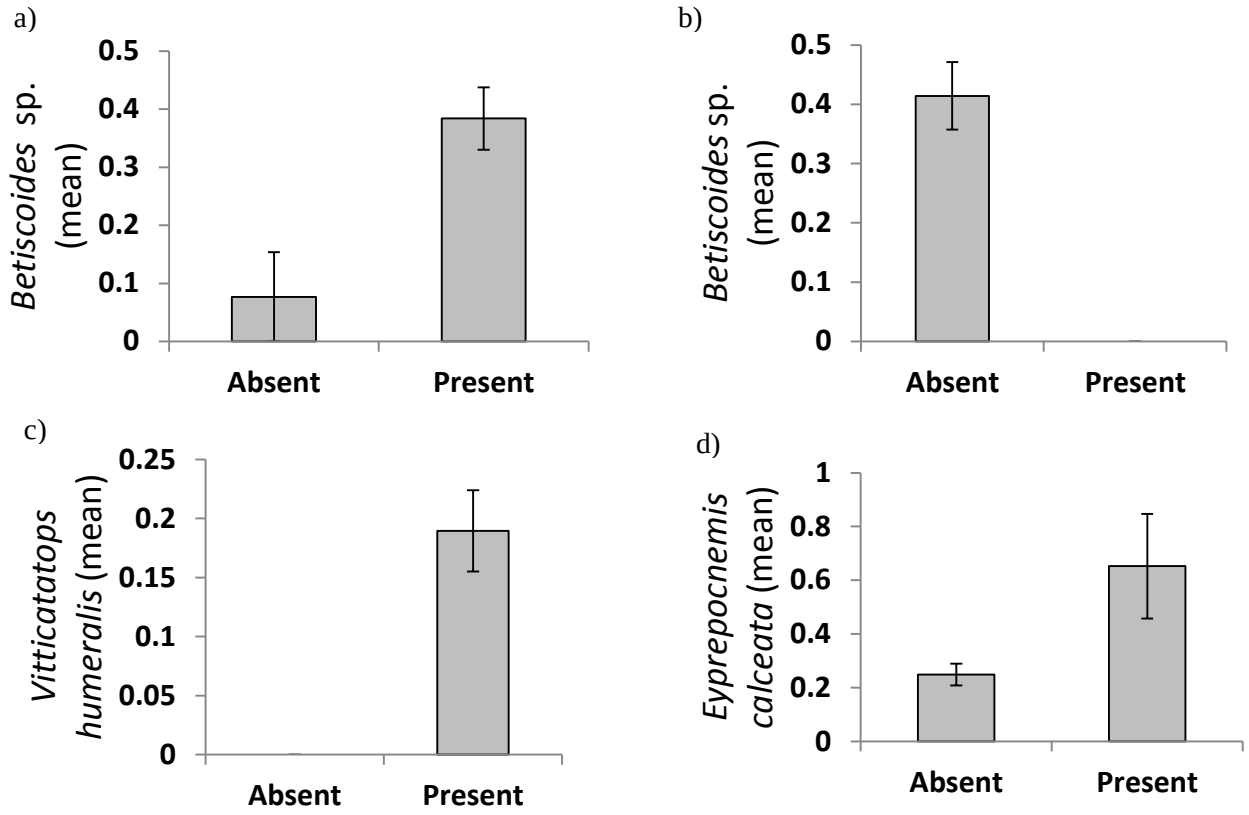
b)



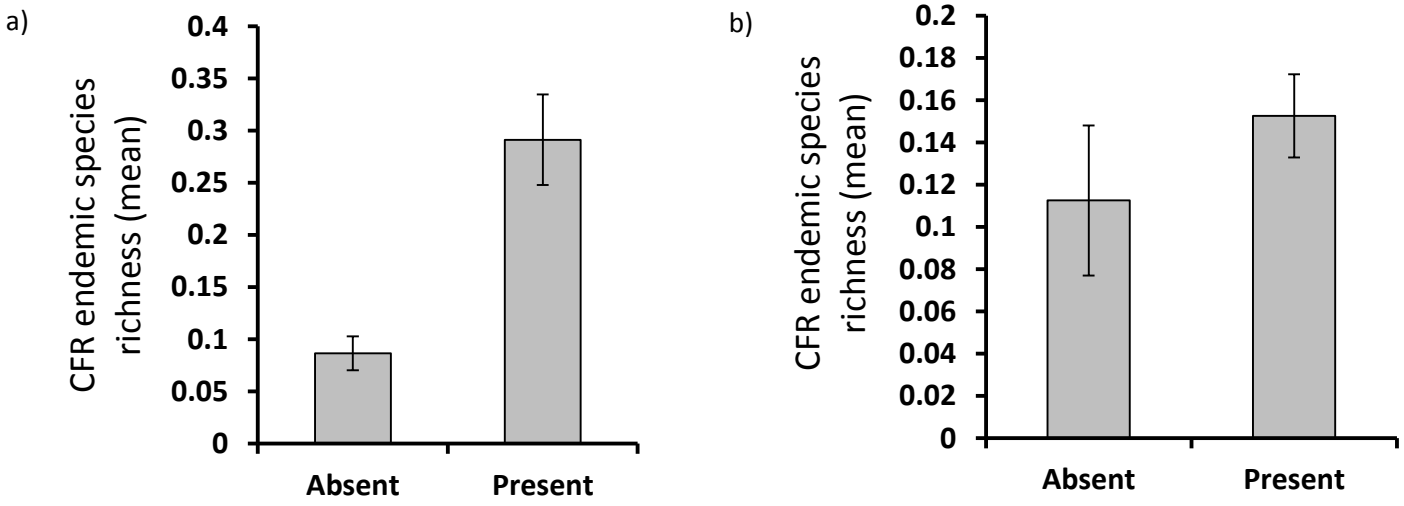
c)



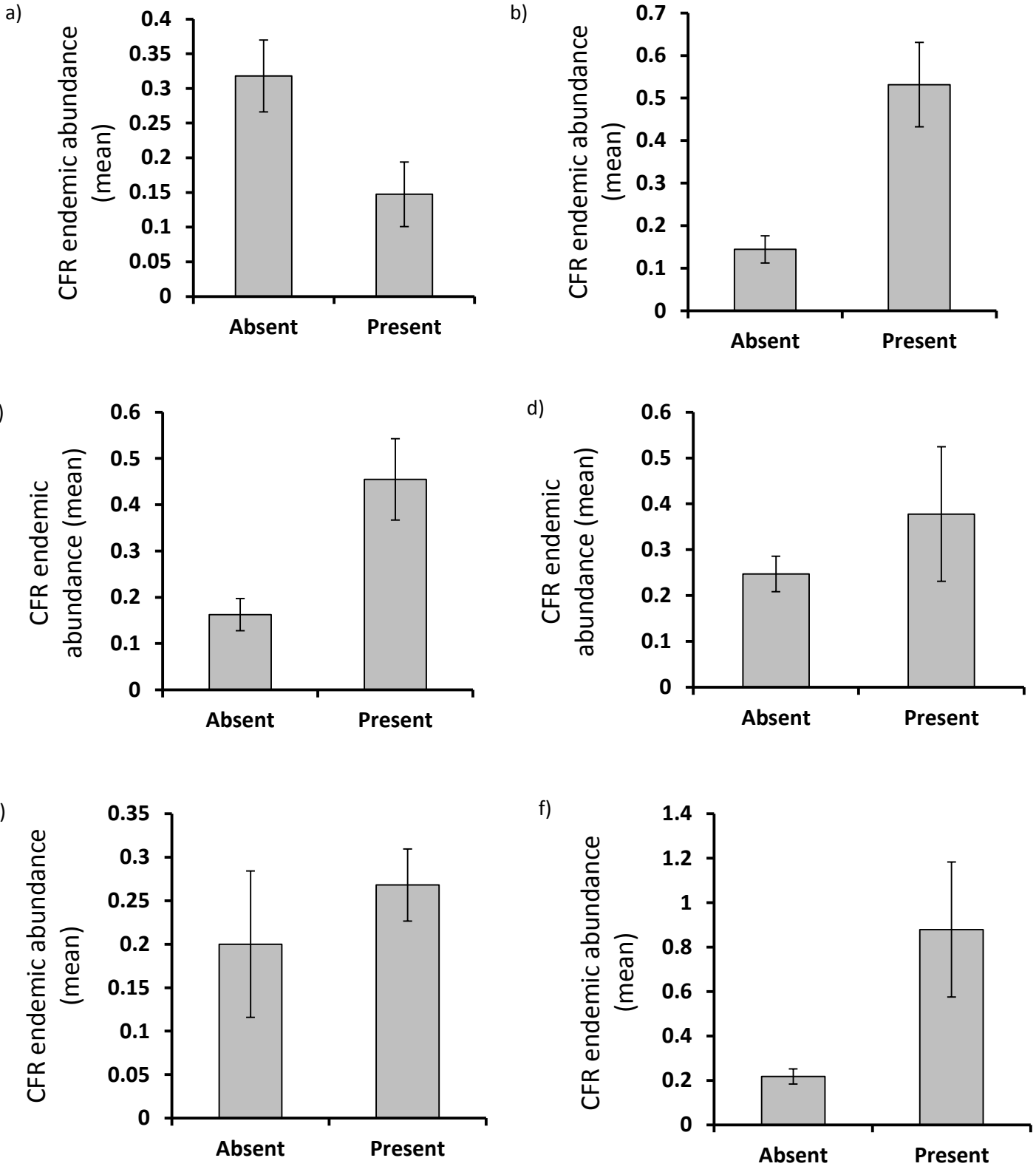
Appendix B. 3. Individual species and their abundance in the presence/absence of certain vegetation growth forms, a) *Betiscoides* sp. and shrub presence, b) *Betiscoides* sp. ad fern presence, c) *Vitticatatops humeralis* and the presence of restio's, d) *Eyprepocnemis calceata* and the presence of trees. (Mean ±1SE).



Appendix B.4. CFR endemic species richness in the presence/absence of a) Shrubs and b) Grass (Mean ±1SE).



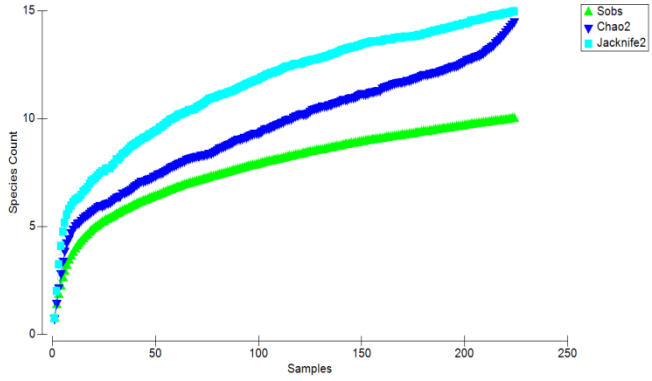
Appendix B.5 CFR endemic species abundance in the presence/absence of a) Trees, b) Shrubs, c) Herbaceous plants, d) Restio, e) Grass and f) Reed (Mean ±1SE).



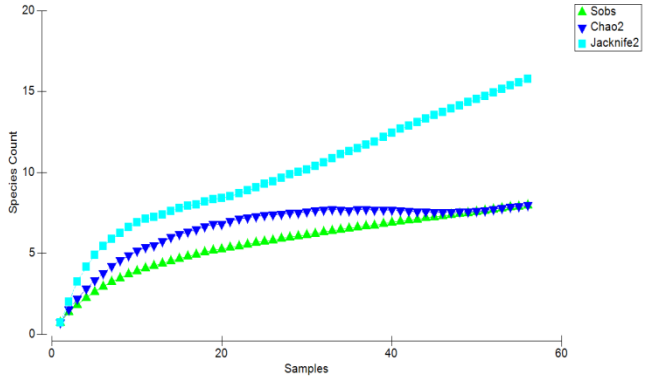
Appendix C. Sampling effort.

Appendix C.1. Species accumulation curves, a) species accumulation curve for the historic, natural riparian and terrestrial zones combined, b) species accumulation curve for only the natural riparian zone, c) species accumulation curve for only the natural terrestrial zone.

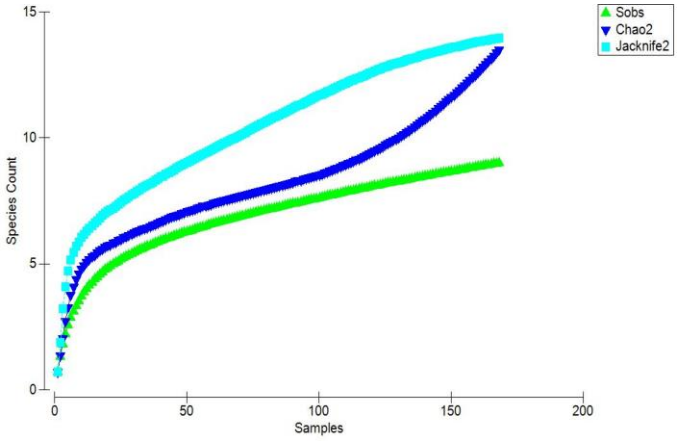
a)



b)

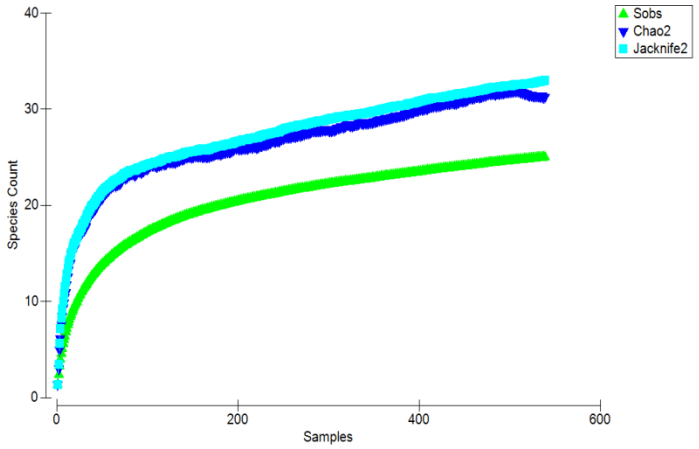


c)

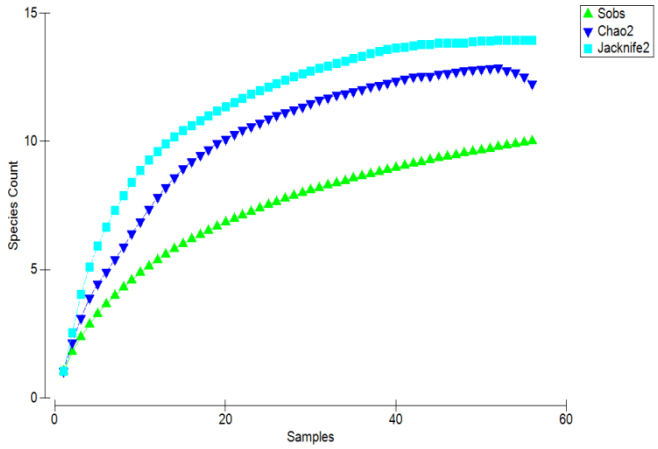


Appendix C.2. Species accumulation curves, a) species accumulation curve of all the land use types b) species accumulation curve for only the natural riparian zone, c) species accumulation curve for only the agricultural riparian zone, d) species accumulation curve for only the cleared riparian zone, e) species accumulation curve for only the invaded riparian zone, f) species accumulation curve for only the urbanized riparian zone.

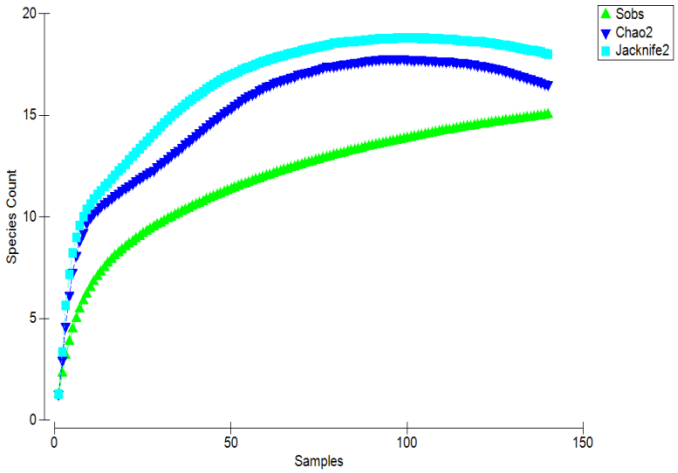
a)



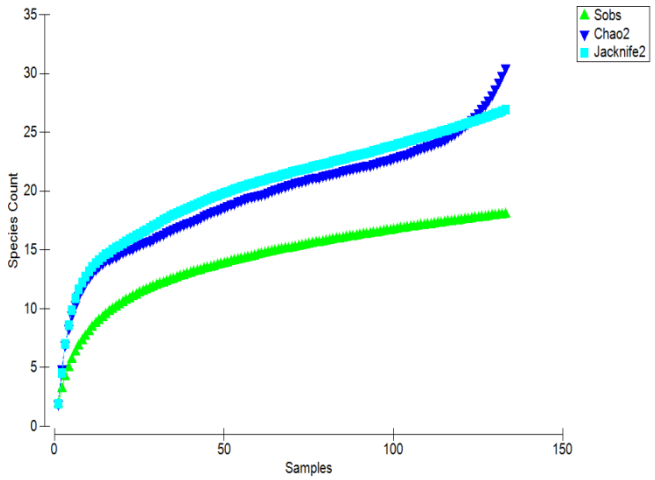
b)



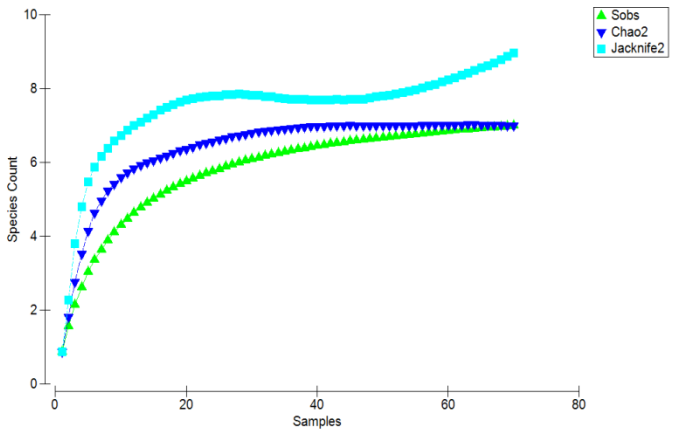
c)



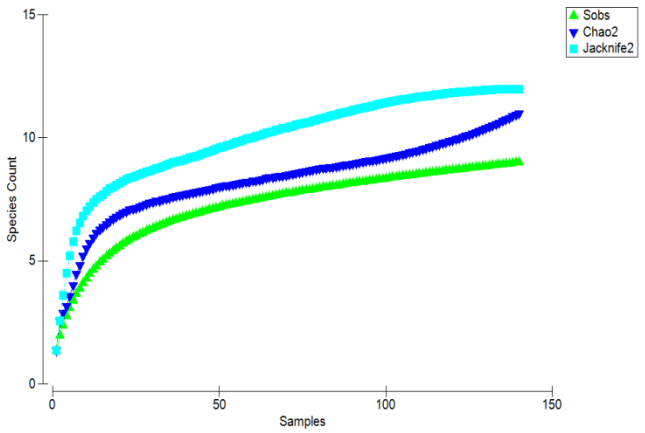
d)



e)



f)



Appendix D. The amount of species and species sampled for each subfamily including their family across all land use types along the riparian corridor.

Family	Subfamily	Species	No. individuals sampled	Distribution
Acrididae	Acridinae	*Acrida* sp. ***	57	Africa
		Keya capicola Uvarov, 1941 *	17	CFR
	Catantopinae	*Frontifissia laevata* Dirsh, 1956 *	1	CFR
		Vitticatantops humeralis (Thunberg, 1815) **	61	Western, Eastern and Northern Cape
	Cyrtacanthacridinae	*Acanthacris ruficornis ruficornis* (Fabricius, 1787) ***	14	Africa
	Euryphyminae	*Calliptamicus semiroseus* (Serville 1838) **	18	Southern Africa
	Eyprepocnemidinae	*Eyprepocnemis calceata* (Serville, 1838) **	329	Southern Africa
	Gomphocerinae	*Anablepia dregei* (Ramme, 1929) **	5	Southern Africa

	Hemiacridinae	*Euloryma umoja* (Spearman, 2013) *	101	CFR
	Oedipodinae	*Acrotylus deustus* (Thunberg, 1815) ***	1	Africa
		Acrotylus patruelis (Herrich-Schäffer, 1838) ***	7	Africa
		Aiolopus thalassinus (Fabricius, 1781) ***	526	Africa
		Gastrimargus verticalis verticalis (Saussure, 1884) **	26	
		Heteropternis pudica (Serville, 1838) **	8	Southern Africa
		Morphacris fasciata (Thunberg, 1815) ***	13	Africa
		Oedaleus nigrofasciatus (De Geer, 1773) ***	5	Africa
		Paracinema tricolor tricolor (Thunberg, 1815) ***	61	Africa
		Scintharista saucia (Stal, 1873) *	1	CFR

		Sphingonotus nigripennis (Serville, 1838) **	2	Western, Eastern and Northern Cape
Lentulidae	Lentulinae	*Betiscoides* sp.*	13	CFR
		Devylderia capensis Dirsh, 1956 *	1	CFR
		Devylderia coryphistoides Sjostedt, 1923 *	2	CFR
		Gymnidium cuneatum (Rehn, 1944) *	3	CFR
Pyrgomorphidae	Pyrgomorphinae	*Atractomorpha acutipennis gerstaeckeri* (Bolivar, 1884) ***	1	Africa
Tettigoniidae	Conocephalinae	*Conocephalus maculatus* (Le Guillou, 1841) ***	90	Africa

(*) CFR endemic species, (**) South African endemic species, (***) African widespread generalist species